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STATE DOCUMENTS

PROCEEDINGS

of

The Montana National Bituminous Conference

Montana Bituminous Conference and National Road Oil and Asphalt Congress

MANY GLACIER HOTEL
GLACIER NATIONAL
PARK

September 7, 8, 9
1937

Montana State Highway Department
and Western Petroleum Refiners
Association

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D. A. McKINNON
State Highway Engineer, Montana State Highway Department
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1937 Montana National Bituminous Conference

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Bituminous Engineer, Montana State Highway Department
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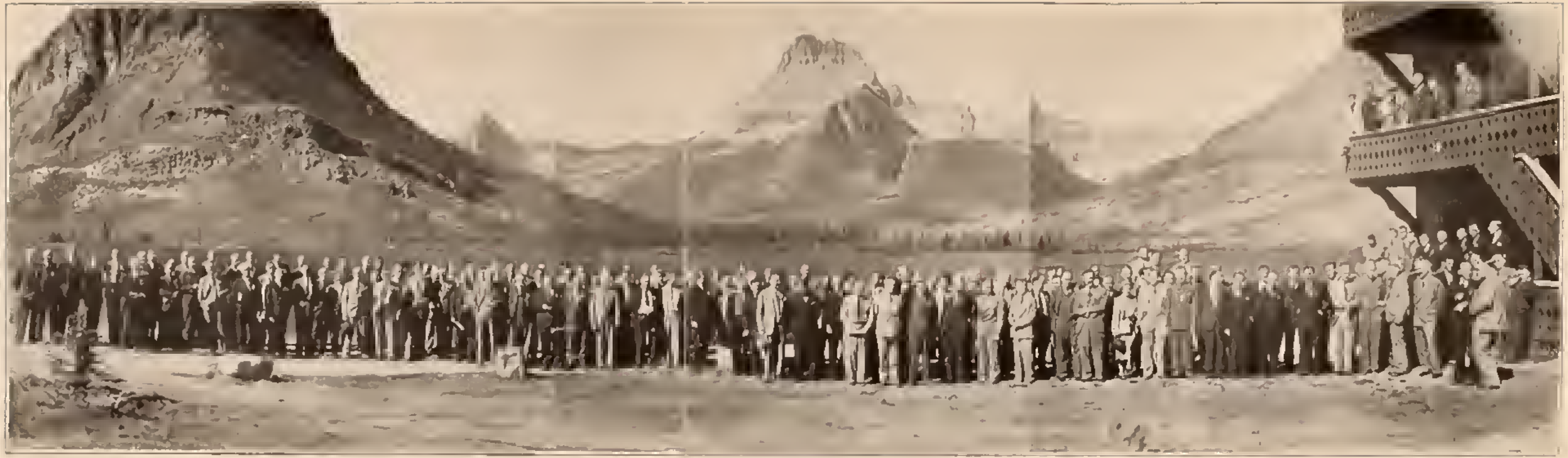

DELEGATES ATTENDING 1927 MONTANA NATIONAL BITUMINOUS CONFERENCE
MANY GLACIER HOTEL, GLACIER NATIONAL PARK

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The Montana National Bituminous Conference

MANY GLACIER HOTEL
Glacier National Park

September 7, 8, 9, 1937

PROCEEDINGS PUBLISHED BY THE STATE OF MONTANA AND THE MONTANA STATE HIGHWAY COMMISSION.

Montana Highway Commission

ROY E. AYERS, Governor
LLOYD A. HAGUE. Chairman
LEE M. FORD, Member JOHN M. WHEELER, Member
D. A. McKINNON, State Highway Engineer

MONTANA STATE OFFICIALS

S. W. Mitchell, Secretary of State
H. J. Freebourn, Attorney General
R. N. Shannon, State Treasurer
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NAEGELE PRINTING CO., HELENA, MONT.

OPENING SESSION

Montana National Bituminous
Conference

Many Glacier Hotel

9:30 A. M.
September 7th, 1937

D. A. McKINNON, Montana State Highway Engineer
Montana Highway Department
General Chairman

D. L. CHENEY, Bituminous Engineer
Montana Highway Department
Assistant General Chairman

G. E. EVERETT, Public Relations Director
Western Petroleum Refiners Association
Assistant General Chairman

OPENING ADDRESS

D. A. McKINNON, General Chairman
State Highway Engineer, Montana Highway Department

As we open this Montana Bituminous Conference, which is a combined meeting of the Third Annual Montana Bituminous Conference and the Sixth National Road Oil and Asphalt Congress, we first wish to express our thanks to all of you people who have made this conference a growing institution. We particularly thank the gentlemen who have put so much time and effort into the preparation of papers and summaries, the committee men who have assisted the chairmen, and the chairmen of the committees who have compiled and have ready the papers to be given at this meeting.

We also want to thank all of you for coming to this conference, many of you coming a great distance. We feel that this conference is going to be bigger than ever and we hope more successful from the standpoint of information gained than the previous conferences.

The method which was used in assembling the material which will be presented here on the many phases of modern bituminous practice has proven very successful as you will agree, I am sure, after you have heard the summaries which will be given by the chairmen. As many of you know the states and provinces known to be interested in bituminous work were requested to assign persons to prepare papers on each of the conference subjects: (1) Research Correlation and Development of a Bituminous Bibliography, (2) Developments in the Fundamentals of Bituminous Construction, (3) Developments in Pracical Design and Construction of Bituminous Surfaces, (4) Maintenance of Bituminous Surfaces.

Each of the subjects comprised a conference section and on each of these a committee was appointed. The papers received from the states were given to the respective committee chairmen and they, with the assistance of the committee members, reviewed and analyzed these papers, preparing from their review a summary on each section which will be presented here. Through this system of assembling the material it has been possible to collect information from all of the states interested with reference to their methods, practices and developments, and to present to you in one paper a comprehensive summary on each section of this very valuable and interesting material.

At the Montana Bituminous Conference held here last year, suggestions and recommendations were made relative to the correlation of research with reference to bituminous practice and materials and to the development of a bituminous bibliography. It was believed by many that much duplication of research work could be eliminated through a more systematic correlation where all departments carrying on research projects could be familiar with and aware of the work under way and planned by others.

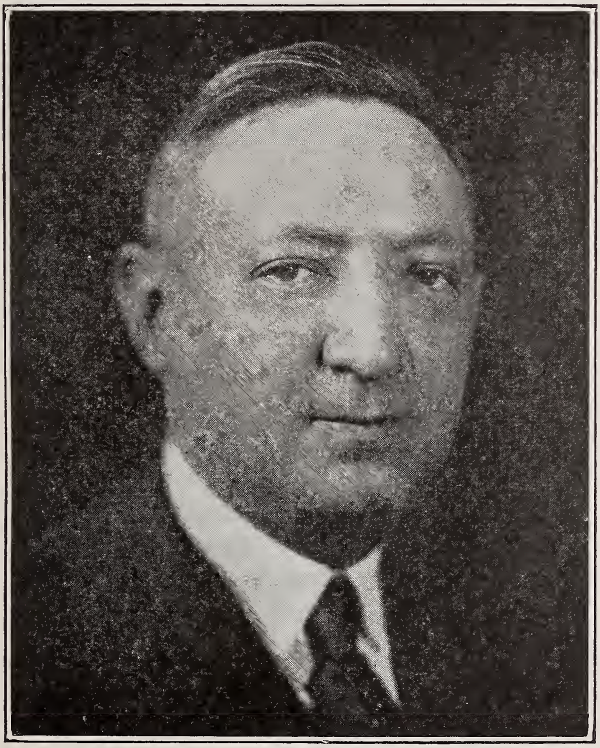
This, then, would make possible, by the elimination of duplication, the carrying out of a much more extensive and valuable research program throughout the states and provinces.

Suggestions with reference to the development of the bituminous bibliography were made by several persons, who believed that an invaluable supply of information and data relative to bituminous practice could be made available to all persons interested through a systematic method of compiling a bibliography containing all published articles and data relative to bituminous work.

The first section of our conference this year has, therefore, been based on the recommendations and suggestions made at the 1936 conference.

ADDRESS TO DELEGATES

B. L. BOYE, President
The Asphalt Institute
New York, New York



As President of The Asphalt Institute, I bring you the cordial greetings of that organization and the assurance that whatever we can do to further the very useful purposes of this Conference we shall do cheerfully and wholeheartedly.

Since Colonel Gray, the Chief Engineer of the Institute, and Messrs. Gilmore, Williamson, and Dan Miller, District Engineers, are taking part in this Conference, I feel that the technical problems will be in safe hands so far as Institute representation is concerned. Primarily, I am hoping that you who are attending this Conference will have your appetites whetted for more, so that you will meet with us at the Annual Asphalt Conference in Memphis during the week of December 6th.

It is a matter of considerable moment that during the calendar years 1934, 1935 and 1936 bituminous highways of all types from surface treatment to hot-mix made up more than 80% of all the state highway construction higher than water-bound macadam. The significance of this showing is that the asphalt highway program has passed beyond the stage of industry promotion and has become a very fundamental concern of the highway departments themselves, for certainly the highway engineers must secure an abundant fund of information concerning ways and means to make this 80% of their total highway program most effective.

Meeting with us at Memphis will be the outstanding figures in the highway engineering profession in the United States and Canada, and the Association of Asphalt Paving Technologists will meet at the same time and place. We are endeavoring, by the most searching preliminary investigation, to bring the discussions directly to bear upon the problems of the most practical importance to the various states and their highway programs, and we need your full co-operation in accomplishing this desired result. Moreover, the contribution which you will make by reason of your splendid accomplishments throughout this section of the country where you have literally made two dollars' worth of highway grow where one grew before will be of untold value to the rest of the country.

The highway program of the nation is being called upon today to justify itself as never before. Large revenues derived from the gas tax are a constant temptation to the politicians and to the powerful lobbies which seek to divert them to other purposes. A sort of whispering campaign is circulating to the effect that we now have enough highways and that the tempo of highway building should be slowed down. The engineer is very much like the farmer in being distinctly an individualist, and an engineering lobby is something practically unheard of. It is therefore exceedingly difficult to combat by an organized counter-offense the subtle and continuing raids upon the highway program. The motorist, who in the last analysis pays the bulk of the highway tax, is strangely apathetic in defending his investment in the great national highway system which has made all Americans neighbors. I hope that at every convention and at every organized demonstration, something will be done to resell good roads to the American people so that we may not go backward after having for so many years so brilliantly gone froward. Our highway system will never be completed, and it will never be safe to slow down our rate of progress because more cars, greater speeds, more concentration of population will always necessitate wider, straighter, safer roads, more miles of secondary or farm-to-market roads, rebuilding, resurfacing, and the sooner the American people realize that the conservation of their investment, the safety of their travel and the economical management of the highway program depends upon there being no let-up in highway building, the sooner we shall have attained and assured a stable prosperity.

SECTION I

Research Correlation and the Development of a Bituminous Bibliography

CHAIRMAN, R. N. TRAXLER, The Barber Asphalt Company
Maurer, New Jeresey

Committee on Bibliography

SUB-CHAIRMAN, G. E. EVERETT, Public Relations Director
Western Petroleum Refiners Association
Tulsa, Oklahoma

WALTER A. AVERILL, Editor, Manager
Pacific Builder & Engineer
Seattle, Washington

J. N. WESTSMITH
National Petroleum News
Los Angeles, California

H. W. RICHARDSON
Engineering News Record
New York City, N. Y.

Committee on Research

SUB-CHAIRMAN, W. S. HOUSEL, Consulting Engineer
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Ann Arbor, Michigan

LEVI MUIR, Materials Engineer
Utah State Road Commission
Salt Lake City, Utah

L. C. KRCHMA, Service Engineer
Asphalt Dept., Socony-Vacuum Oil Co.
Kansas City, Missouri

Review of Papers Prepared on Development of a Bituminous Bibliography.

By

G. E. EVERETT, Director Public Relations
Western Petroleum Refiners Association, Tulsa, Oklahoma

Assistant General Chairman,
Montana National Bituminous Conference

The best index to the general interest in any particular subject probably is found in the tendency of the subject to evoke discussion and argument. If this be true, then the subject of a bituminous bibliography has earned its place on the program of this conference.

Opinions expressed on the subject have been most emphatic —in fact almost violent—and if they could be illustrated diagramatically they would be shown in almost vertical lines. At one end of the scale would be plotted the belief that the subject is of sufficient importance to warrant the establishment of an organization which should have the specific and exclusive duties of compiling, maintaining and distributing a comprehensive, international bibliography of bituminous literature.

At the other end of the scale would be plotted the belief, equally emphatic that this conference can do little to duplicate or even approach the work being done by agencies already in the field. To determine the weighted average of the opinions expressed is difficult but it would be plotted somewhere between the two extremes with a strong tendency to favor a continuance of present methods and agencies, limiting action of this conference to suggestions for expanding and improving the work already being done.

This latter opinion is probably best expressed in the language of Mr. Housel of Michigan, a member of the subcommittee on Research Correlation. Mr. Housel has this to say:

"I cannot see how members of this conference, who must regard this work as more or less casual, can hope to duplicate, or even approach the work that is already being done, regardless of its shortcomings.

"The Bureau of Public Roads publishes a weekly bulletin entitled 'Highways' which reviews a large number of current periodicals published in this country and abroad. There are also the Quarterly Digests published by the Asphalt Institute which appear to be organized for greater continuity than the Montana Conference might achieve.

"There is also the Engineering Index Service which makes an extensive review of current periodicals on selected subjects which might be purchased for the conference at an expense which would, in all probability be much less than the time and money the committee might spend in the work. I have reviewed the Index Service (still quoting Mr. House) and believe we might consider the possibility of the following sections:

Section 17—Bituminous Materials	$ 9.00
Section 179—Roads & Streets	40.00
Section 192—Soils	7.00
Section 273—Road Materials	9.00

Mr. Housel then suggests that, if the conference is really serious concerning the question of a bibliography the Sections of the Engineering Index mentioned be subscribed for and that the weekly index cards listing articles on bituminous subjects be studied by a committee and that the committee go just as far as it likes in disseminating the information to the members of the conference, or in including it in the publication of the annual proceedings.

Mr. Housel's suggestions, it appears to your chairman, are most constructive and present a challenge to the conference. I anticipate a lively discussion from the floor.

All those who have advanced suggestions for the improvement of our bituminous bibliography have mentioned the present service performed by the Asphalt Institute and the Highway Research Board. Although imperfections are seen in the work of both those organizations they have been extremely helpful to the bituminous engineer and the technologist.

Several specific suggestions concerning those works appear worthy of consideration here.

1. It has been suggested that both the Institute and the Research Board would perform a real service if they could compile a summary of the periodic digests and abstracts for a period of perhaps the last three or five years, thus concentrating in one publication the best writings on bituminous subjects in recent years.
2. The thought that perhaps the Institute and the Research Board should combine their efforts into one publication, publish more frequently, covering more publications and giving their digests in greater detail has been advanced. As a counter suggestion it was pointed out that a true bibliography should do little more than indicate the type of the article reviewed as it is impossible and impractical to have some one else do your reading for you.
3. In order to bring the subject of a bibliography closer to the realm of this conference it was suggested that perhaps the conference should appoint a permanent bibliography committee whose members would be assigned specific publications to review and digest, and that the actual work of publication be assumed by the Research Board of the Asphalt Institute. The feeling behind this suggestion was

that more publications could be considered, the reviews might be more comprehensive, more up-to-date, and that the organization which undertook publication would be relieved of much of the detail and some expense. An obstacle to the practical carrying out of this suggestion would be the desire of either of those organizations to reorganize their own methods and routine to the extent necessary, and their desire for outside assistance. There would be too, a lack of uniformity of style and presentation were the digests to be prepared by many authors rather than one, as is probably the case in the present digests and abstracts. The abstracts and digests now available are limited almost entirely to bituminous literature appearing in the regularly published periodicals — the monthly and weekly magazines devoted to highway problems, printed records of highway conferences, etc. There is probably an even greater volume of information, of a varying degree of usefulness and authenticity, which never attains the dignity of formal publication. This material lies buried, but much of it easily available, in the files of our highway departments, the engineering departments of our universities and in petroleum laboratories. Some of it is confidential but much of it deals with local or regional research projects and constitutes a wealth of information to the bituminous engineer if properly selected and digested. In other words the bibliographies now published do not exhaust all sources of material and probably for reasons beyond their control. Perhaps the conference can obtain access to material not now available to the established bibliographical agencies.

Another suggestion which appears to have considerable merit and the possibility of pracical application, concerns the preparation and distribution of a questionnaire designed to determine the magazines most read by the bituminous engineer and technologist and to classify his interests according to primary and secondary subjects.

The proposed questionnaire would classify the road types in which most engineers are interested as:

A. Stabilization
B. Surface Treatment
C. Bituminous Mats
D. Bituminous Concrete and Sheet Asphalt

It would inquire where the most useful and usable information is found concerning:

- A. Testing Methods
- B. Testing Equipment
- C. Construction Methods
- D. Mixture Design
- E. Construction Equipment

It would ask further for the list of publications now read.

The proposed questionnaire could be expanded to any practical length and could be made to produce information concerning the tendency of bituminous highways to increase or decrease, tentative estimates of the mileage under construction and contemplated and other general and useful information.

The task of preparing and distributing the questionnaire and classifying and making known the results appears to be one which might be well considered by this conference.

The fact that this committee is divided into two sections—The Correlation of Research and the Development of Bituminous Bibliography—indicates the close interdependence of the two subjects. Any true research project is practically worthless without the publication medium to give it distribution and a wide reading. Likewise research loses much of its value without correlation. Bibliography can be made to play an important part in that correlation with some method of cross reference which will direct attention to research projects which appear to indicate varying conclusions.

Frequently the conclusions arrived at in an extremely worthwhile research project are lost or at least minimized because of a faulty bibliography on the subject or because of the author's poor selection of the medium in which his findings are published. We feel, therefore, that Research and Bibliography while treated here as separate subjects, must be considered fundamentally as one subject. Any conclusions reached at the conference on the subject of Bibliography should be considered carefully in connection with similar conclusions concerning the general subject of Research.

SUMMARY

Summarizing the opinions expressed by committee members and attempting to bring specific recommendations to the conference we find that:

1. Although there is some feeling that this conference should undertake the task of preparing and distributing a comprehensive bibliography of bituminous literature, the preponderance of opinion is that such a project would prove impractical and largely an unsatisfactory duplication of present work. Your committee does not recommend such an undertaking.

2. To conference members seeking sources of publication of the most useful and most recent information on bituminous literature your committee suggests reference to the bibliographies, digests and abstracts now available.

   The Quarterly Digest of Asphalt Literature of the Asphalt Institute

   The Asphalt Forum, published by the Pacific Coast Division of the Asphalt Institute

   The Abstracts of the Highway Research Board, published monthly

   The Engineering Index Service, available at subscription prices and when available

   The Subject Index or Bibliography, soon to be available

3. Your committee suggests the appointment of a committee to study the present bibliographies and to recommend to the agencies of publication ways in which they can be improved and adapted to the needs of conference members.

4. Your committee urges the co-operation of conference members with those agencies now publishing bibliographies and digests by making available to them reports, articles and other writings which might not be received through regular channels and which might be appropriate for inclusions in those bibliographies now published and contemplated.

Conference on the Development of a Bituminous Bibliography.

CHAIRMAN, R. N. TRAXLER
The Barber Asphalt Company
Maurer, N. J.

Conference Board

BAILEY TREMPER, Materials Engineer
Washington Department of Highways
Olympia, Washington

CARL R. REID, Materials Engineer
Oklahoma State Highway Commission
Oklahoma City, Oklahoma

RAYMOND HARSCH, Asphalt Department
Shell Oil Company
San Francisco, California

EMBY KAYE, Vice-President
Skelly Oil Company
Tulsa, Oklahoma

T. R. CORBETT, Chief Chemist
Yale Oil Corporation
Billings, Montana

Mr. Traxler: We have here this morning several members of the American Association of State Highway Officials. This organization plans to publish a volume containing bibliographies and research correlations gathered in past years. The book will be in circulation this winter. Will Mr. Reagel of the Missouri State Highway Department, who is chairman of the committee in charge of this work, please tell us something about it?

Mr. Reagel:
Missouri

The American Association of State Highway Officials has a committee that seems to have practically the same purpose as your committee, designated as the committee on research activities. For some seven or eight years this committee published a current digest of research performed by highway engineering departments. Two or three years ago the activities of this committee lapsed, but it has been reorganized with the function of the committee to produce a bibliography of highway research and the first bibliography is being obtained from highway departments, supplemented by information obtained from major schools and colleges. Following a policy of the Highway Officials for all their standing committees, a permanent secretary has been appointed for this committee, and that secretary is Mr. Crum, director of the Highway Research Board, which provides excellent cooperation between two organizations which are interested in this subject. Mr. Crum is also obtaining the information from schools and colleges. At present the data will consist only of a subject index or bibliography, but what it might grow into a little later we do not know. At present it is entirely confined to information that can be obtained from highway departments and schools.

We can see that this data is going to be incomplete because already we are being offered bibliographies from the commercial field, and I think that at the next meeting the committee's work will be enlarged to include commercial work and subject matter obtained that way. The question is also going to be raised as to whether we should confine ourselves to a bibliography, or include some short descriptive abstracts.

Now we are glad to co-operate in any way that we can with this organization. If they wish to make use of the work we are doing, or if there is any way we can better it, we would be glad to have them supplement our work.

I also take this opportunity to urge members of the various highway departments to submit information that has been requested to us as rapidly as possible so that we can complete the first bibliography early in the winter.

Mr. Traxler: We now have some time for discussion and we want the discussion to be hearty and complete.

Prof. Emmons:
Michigan

I should like to ask if this bibliography which Mr. Reagel is preparing will be generally available. I believe in the past it was obtainable only by state highway departments.

Mr. Reagel:
Missouri

That is correct. It was not a bibliography before. It was a current digest, but, as I understand, in its new form it will be made available to anyone. It will certainly be put in the hands of the highway research board and could be obtained through them. I am certain it will be available to members of this conference as we wish to have as wide a distribution as possible.

Prof. Lang:
Minnesota

I think one of our difficulties with these bibliographies is the finding of what we are looking for. The accumulation of bibliographies on past research is rather voluminous, and if you want to find one specific item there is difficulty if you don't know just where to look for it. I would like to suggest to Mr. Reagel's committee that they give considerable thought to the indexes. If we could find bituminous subjects in one part of the index—perhaps under low cost roads or something pertaining to that—it would be of help.

Mr. Reagel: Missouri

That was expressed in the committee last evening—that perhaps a separate section be put in. If we could get sufficient co-operation from the bituminous people so that a separate bituminous section could be produced, provided it were large enough, I think that it could be produced separately. We don't know what this is going to grow into; it is going to be rather lame—our first issue. But it is going to be amplified, and the first one will be a rallying point for that type of information. If it is desirable, a separate section could be reprinted separately.

Mr. Traxler:

Professor Lang's comments concerning an index are timely. A bibliography containing an index would be most useful. It is a great task to thumb through a volume of bibliographic material in order to find a particular subject. And now will the committee make some comments and suggestions concerning the indexing of bibliographies that now exist? Does anyone have ideas they would like to express? On such a peppy morning we should be full of ideas. What do the members of the conference board think?

Mr. Harsch: California

I have a thought that some method of eliminating duplication should be worked out. At the present time The Asphalt Institute in New York prepares a quarterly digest and the Pacific Coast Division of The Asphalt Institute prepares a bibliography published in The Asphalt Forum. There is some duplication. There is possibly some duplication between other agencies. If that could be eliminated, there would be considerable saving of time and cost.

Mr. Traxler: That is an excellent suggestion from the standpoint of economy. Undoubtedly, there is duplication if you compare the bibliographies put out by the Highway Research Board and those prepared by The Asphalt Institute. When Mr. Reagel's committee of the A.A.S.H.O. starts functioning there again will be a certain amount of duplication. The problem is a difficult one unless you have all activity combined under one organization and in one publication, but the elimination of duplication to as great an extent as possible certainly is an ideal which should be considered.

Mr. Harsch:
California

Would it be possible to separate the bibliographies; have one on research and one on practices?

Mr. Traxler: Can we have some discussion of that problem? Can you establish a definite line of demarcation between research and construction? Of course the development of a correlation between research and construction problems is supposed to be the object and duty of this committee.

Prof. Lang
Minnesota

One of the difficulties encountered in going through a bibliography is the inability to identify the particular articles that will be of special interest to the reader. Many of the articles, even though the title might otherwise indicate, do not contain the information we expected to find in them. Often-times the articles as written by research workers become rather long and involved, and in the writer's interest in detail the primary objective is lost sight of.

What I'm getting at is this: I don't presume it is practical, but if we could have a short abstract of the article and what it contains, it would be of considerable help to a man who wished to obtain knowledge from research articles. If the man in the bituminous field could have not only a bibliography but a short abstract of the article then he would know whether he wished to read it.

Mr. Traxler: Your committee has given that subject considerable thought. A big problem is presented if you try to abstract every subject; the publication will run into many volumes. And yet, the mere listing of a subject isn't of much help because frequently the titles of the publications do not give an adequate idea of the subject matter. It is a difficult problem to summarize a technical paper and make the abstract complete enough to be helpful and still keep it within the limits of practicability.

Mr. Black:
Illinois

I appreciate very much Mr. Lang's comment on that. I think any of us who have ever attempted any research are confronted with that very thing, seeing a whole string of lists and not being able to judge the details. I understand that it is very difficult to print the abstracts that we would like to have, but it seems to me, assuming that we can't get the abstracts, we might give a list of main points in each article which would indicate whether it is broad in scope or whether it goes into the minute detail of some special field. The titles too often do not disclose these facts. That is just a suggestion for the committee.

Mr. Lee:
Texas

I find that in either discussion or reading articles it takes about a tenth of your time to determine when you are talking about the same thing because of the lack of standardization of terms. You go into an article and it takes considerable time to get on common footing to find out if you are talking about the same thing but using different terms. If a movement could be started which would standardize terms, or if a movement could be started which would standardize our terms, I think it would simplify future articles.

Mr. Traxler: Some of you construction men might tell us what you think would be an advisable way of getting this information, these new facts, to you in usable form. The ideal situation is to read the article but you cannot read them all. The great mass of literature must be condensed in some way. Mr. Tremper, do you have any suggestions?

Mr. Tremper:
Washington

The only thought I have on the subject is what has been mentioned several times this morning, and that is the difficulty of learning from the title of an article whether it has the information you are looking for and also the other angle—that often a thing is passed up for the simple reason that a person doesn't realize from the title that the subject matter in which he is interested appears in the article. If the committee preparing bibliographies did nothing else than amplify the titles, making a sort of very brief table of contents, it would be very helpful. And the matter of having an index so that it could be more readily ascertained as to where the particular subject could be found would be very helpful.

Mr. Porak:
Washington

I am very much inclined to agree with Mr. Tremper. Certainly if you have a bibliography, the selection of some article that appears to be applicable to your own problem is the first step. Then you must go to the original article, and it very often takes considerable time and in some cases involves expense to get it. Consequently, the more information that can be included in the bibliography, the more helpful it is going to be.

Mr. Traxler: Anyone else? I wonder if we could have some expressions of opinion from the Bureau of Public Roads?

Mr. Benedict:
Bureau of
Public Roads

In summarizing the papers for the fundamentals section of this conference, we of the committee reviewed all of the 23 papers independently, selecting and stating briefly what we considered to be the principal points in each. It is interesting to notice that all members picked out almost exactly the same points. Therefore, I concur in the expressions that have been made here that any article can be boiled down to a few concise, pithy statements that will take only a short time to read and yet will miss none of the essential facts presented.

Mr. Hveem:
California

I rather question to some extent the application of abstracts. It has been my experience that abstracts of an article made by someone else often misses some particular point in which I might be interested. I believe it is better to get the classification of the article from the index and read the entire paper to get the information.

Prof. Lang:
Minnesota

The abstract, remember, is not a reprint of the article. An abstract is a synopsis designed to permit the reader to determine whether the article will be of interest to him. Many articles are rather long.

Mr. Traxler:

It is discouraging to have only a list of subjects. Sometimes an entire day is spent in the library looking up articles of which we have only the subject. We are justly disapponited when no useful information is obtained. However, a short sentence or two would have given us some clue as to the general content of each paper. The abstracter should not attempt to read the article for you; he should endeavor to indicate the subject discussed and the conclusions arrived at.

Mr. Krchma:
Missouri

It would appear to me that present agencies could supplement each other and give us all the information we require. Mr. Reagel's index on highway materials would cover all phases of construction, including bituminous work. It would appear that if The Asphalt Institute and similar agencies interested went to this index and saw the material that was covered in it and would then abstract it, Mr. Lang's requirements would be well filled. It doesn't seem necessary to have any further agencies doing this work. Abstracts at best are difficult, but it would be impossible to abstract all the literature as indexed by the Highway Officials' Index. The volume would be too large. But some agency that deals in bituminous materials, such as The Asphalt Institute, could readily abstract the index. A simple policy like this could give the gist of the information in the article so you would know whether it is worth reading.

Mr. McKesson: California
It seems to me, listening to this discussion, it might be of considerable value if a practice were started which would require the author to prepare a summary which is printed at the beginning of his paper, and if that were done as a universal practice, it would be helpful in eliminating some of the difficulties that were discussed here this morning. If the Bituminous Conference couldn't start some such practice as this, your committee might recommend to various engineering publications that they have either the editor print indexes prepared by him or require the author presenting the paper to digest his own article. The author presumably could digest the article better than another reader. If they would try to establish such a practice throughout the engineering world, I think that would simplify the problems you are discussing here today. The Bituminous Conference could start this just as well as anyone else.

Mr. Traxler: That idea was discussed last night at our committee meeting. The American Chemical Society demands a synopsis or abstract prepared by the author and placed at the beginning of each article. The American Institute of Physics, the American Ceramics Society, and numerous other organizations are beginning to insist that every original contribution to their journals be preceded by an abstract or synopsis. It certainly will be well worthwhile for the Bituminous Conference to do whatever they can to increase that practice. Is there further discussion?

Mr. Harsch:
California

Mr. Chairman, I would like to hear from the press. The engineering press could be a vital influence on this one problem if they are willing to adopt such a practice.

Mr. Traxler:

We have several members of the press on our committee; their reactions were obtained last night in committee meeting. Mr. Ballard of Western Construction News, would you care to say anything to the conference?

Mr. Ballard:
California

On that subject I would like to differentiate between the conception of a paper and an article. Maybe it is a fine point, but I picture a paper as a presentation that appears in the A.S.T.M. or A.S.C.E. proceedings as distinguished from the articles that appear in the average technical magazine. The technical paper, I believe, should have a synopsis because it often runs into great lengths and goes into considerable detail, as some of the gentlemen have already pointed out. For this reason, it really should have the essentials boiled down into a synopsis that gives the essence of the paper.

I find in editing, a good many engineers have a tendency not to go directly into the subject. They give the whereases and wherefores and qualifications before they finally get down to the essence of what they are talking about. I believe we should encourage those who write technical papers, taking sixteen pages more or less, to put the essence of the paper in abstract form so that the average reader can ascertain whether he wants to go on.

As distinguished from that, the magazine articles are short by comparison—you won't find them longer than two or three thousand words on the average—and they are usually accompanied by pictures, illustrations and diagrams to assist in indicating what is contained in the article. Furthermore, if the editing is done correctly, I think you will find the first paragraph contains the essence of the article. In other words, an abstract would do nothing more than repeat what is contained in the first paragraph of the article. So in reading your technical magazine, if you read the first paragraphs, you will find there the essence or lead material of the article. So, from my point of view, the abstract of an article in a technical magazine can be considered equivalent to the opening paragraph.

Mr. Traxler: Gentlemen, do you wish to take any action on the recommendations set forth by Mr. Everett?

Prof. Lang:
Minnesota
Mr. Chairman, I would like to ask about the committee he recommends be appointed—how many would there be on that committee?

Mr. Traxler: We did not believe it to be our duty to go so far as to recommend the size of the committee. However, I think the committee should be small.

Prof. Lang:
Minnesota
Merely as a suggestion, I would suggest a committee of five.

Mr. Nevitt:
Missouri
I think Professor Lang's suggestion excellent, but it would seem to me that the size of the committee, the set-up of its organization, and other such details should be left to the organization of the conference next year. In other words, it would be the committee on bibliography of research next year. I am merely seconding the recommendations of the committee.

Prof. Lang:
Minnesota
That was really my idea and I only made a suggestion of a committee of five.

Mr. Traxler: It has been moved and seconded that the conference appoint a committee to carry out the recommendations and suggestions presented to you here this morning by Mr. Everett for the committee on bibliography. Is there any further discussion? If not, all in favor signify by saying aye; those opposed? The motion is carried. I anticipate considerable discussion in groups, in the halls and lobby, concerning the subject of bituminous bibliography. Please feel free to approach any member of the committee and give them the benefit of your ideas.

Review of Papers Prepared on Correlation of Research.

By

W. S. HOUSEL, Research Consultant
Michigan State Highway Department
Ann Arbor, Michigan

Seven papers were submitted on the general subject of progress in research. The titles of the papers and the authors are as follows:

"Bituminous Research in Kansas" by J. R. Benson, Bituminous Engineer, Kansas State Highway Department.

"Progress in Research Plans, the Correlation of Research, Developments in the Fundamentals and Construction of Bituminous Surfaces in North Dakota" by H. G. Groves, Bituminous and Soils Engineer, North Dakota State Highway Department.

"Progress in Research" by Bailey Tremper, Materials Engineer, Washington Department of Highways.

"Progress in Research Plans and Correlation of Research in Bituminous Construction" by Ira E. Russell, Materials Engineer, Wyoming State Highway Department.

"Bituminous Research in Nebraska" by R. E. Bollen, Assistant Testing Engineer, Department of Roads and Irrigation, Nebraska.

"A Correlation of Research to Practice in Bituminous Surfacing" by N. M. Finkbiner, Engineer of Materials, Oregon State Highway Commission.

"Research Correlation and Development of a Bituminous Bibliography" by Seward Mason, Testing Engineer, Montana Highway Department.

The various authors' interpretation of the subject differed somewhat but in the main they have indicated to what extent research has entered into the actual construction of bituminous roads. Generally speaking, it appears that up to the present time research has been more or less incidental to construction. The pressure of buidling roads now and the limited funds available have not permitted a carefully planned program of fundamental research. This situation is not strange nor does it indicate any failure to appreciate the value of research as the basis of sound design. It may be said that it is absolutely necessary to go through a period of more or less blind experimentation in order to discover the weaknesses which must be remedied and to determine just what the problems are that must be solved by the research worker.

Even the most ardent research enthusiast would not attempt to outline a program of fundamental research designed to determine how to build the perfect road before any roads of the type in question had been built and had failed. It is hoped that the experimental stage has extended over a sufficient period to expose the major problems and that research may now concentrate on them and produce the more adequate criteria necessary for the best design and construction methods.

It is not possible in reviewing these papers to cover them adequately in the short time available and in justice to the authors the papers themselves should be studied carefully. In most cases these papers have been condensed to cover a large subject in a short space and should not be further reduced. The writer, therefore, has attempted to conserve time for discussion, by pointing out those features of each paper which impressed him as being important to the correlation of research with bituminous construction.

There are several subjects which appear to be of widespread interest as they are mentioned in several of the papers, and in some cases, discussed at length. Rated in the order of the attention they received these subjects appear to be as follows:

1. Changes in the physical properties of bituminous materials due to
    - (a) Aging in service
    - (b) Exposure during construction
    - (c) Accelerated changes of bituminous material in thin films on mineral aggregates.
2. Adhesion phenomena and replacement of bituminous films by water.
3. Construction of adequate bases or other methods of eliminating poor subgrade conditions.
4. Relative merits of slow and medium curing asphaltic oils.
5. Effect of type and percentage of mineral filler on stability of bituminous mixtures.
6. Relative merits of road mix and plant mix construction.

In the paper by Mr. Benson are presented results of a comprehensive study of bituminous construction in Kansas. The study of the bituminous materials and physical changes in them after being placed in service appears to be of first importance particularly when correlated with service behavior of the mat itself. Early investigations indicated that asphalt with a high solubility in carbon tetrachloride were producing better quality surfaces, and the same was true of those materials with a good ductility when reduced to low penetrations either in service or by artificial means.

In 1936 an investigation was begun of medium curing cutback materials extracted from mats in service from 9 to 11 months. Even in this short period of time rather startling reductions were noted in penetration and ductility of the asphaltic residues recovered from the surface over the distillation residues of the original asphaltic oil. As a result any superiority of MC asphalts over the SC types in regards to serviceability was seriously quesitoned.

Mr. Benson discusses the relative merits of medium curing and slow curing asphaltic oils, listing as advantages of the MC oils:

1. A less critical asphalt content making possible a wider variation in aggregates used without undue loss of stability, particularly in loosely graded or open type mixtures.

2. Decrease in the danger of stripping of asphaltic films by water action.
3. Shorter curing periods.

The disadvantages of the medium curing cut-backs as compared to the slow curing oils brought out in the paper appear to be as follows:

1. Excessive hardening of the MC asphaltic oil due to loss of volatile matter and perhaps other physical changes.
2. Higher cost.
3. Lack of ability to adjust itself to minor changes in the supporting base without destruction of its structure, resulting in cracking and raveling of the surface.
4. Danger of ''under-asphalting'' the bituminous mixtures by engineers experienced in the use of slow curing oils.

The last objection is of particular interest from the research viewpoint as it brings out a common danger of relying on practical judgment in dealing with different types of materials, in the place of positive criteria based on adequate investigation and formulated in terms which do not depend upon vague rule-of-thumb procedure. In all fairness it should be said that the engineer or at least the inadequacy of present information was at fault rather than the material.

It is brought out in the discussion that slow curing oils apparently retain their fluid properties for much longer periods of time than the medium curing products. This observation is in accord with experience in Michigan which has shown that the slow curing oils have retained their fluid characteristics over two years service to a surprising degree.

A second major factor in failures of bituminous surfaces is listed as subgrade and base failures. Mr. Benson believes that the effect of poor subgrade may be eliminated by soil stabilization in some cases and by proper drainage and protection from surface moisture in a number of others. The construction of an adequate base as the main structural element in all cases is taken to be an essential requirement. It is noted that edge failures constitute a large maintenance item, a fact which has been mentioned by several states, which as a result have adopted the procedure of building the base course from 1 foot to 1½ feet beyond the edge of the bituminous mat. With vehicles frequently driving off the traffic lane onto the shoulders, and perhaps more frequently riding the edge, it is not strange that this point of greatest weakness should have occasioned many failures.

Mr. Groves in discussing bituminous construction in North Dakota ascribes most of the failures to poor subgrades and inadequate bases and notes particularly the prevailence of edge failures. In this state the old 3-inch base course with even thinner edges is being replaced by a stabilized gravel base 3 feet wider than the bituminous mat. The base is built in two layers of proper proportions of gravel and soil binder which are compacted by pneumatic tire rollers and smooth steel rollers for the top course. Water is used as an aid to compaction although in some cases difficulty has been encountered due to excess moisture causing pumping of the soil mortar. Standard thicknesses of compacted base are 5½ inches over cohesive soils and 4 inches over good quality granular soils.

Mr. Groves also noted the trend toward the use of plant mix to supplant road mix in the construction, both of bases and bituminous wearing surfaces. The advantages of the plant mix were given as closer control, possibility of using higher viscosity oils and less dependence on weather conditions, thereby extending the construction season.

The writer feels that the paper has given several significant trends in construction practice which appear amply justified by fundamental research. The necessity of an adequate base course designed for specific subgrade conditions seems so obvious as to need no particular emphasis, but nevertheleses such proceduree is an exception rather than the rule. The superiority of the sand subgrade over the clay particularly during wet periods can be easily demonstrated and the lighter base should bring about a considerable economy.

It also follows logically that bases designed as the main structural element in the surface should be carefully proportioned and compacted to produce their highest stability. It might be suggested at this point that difficulties with moisture could be eliminated and even more efficient compaction procured by a determination of optimum moisture content followed with the proper control in the field. Finally it may be said, that given a structurally sufficient base the lighter wearing surfaces which Mr. Groves suggests in his paper may be perfectly ample and would result in the sort of intelligent economy which should be a characteristic of engineering.

The outstanding feature of research in the state of Washington as described by Mr. Tremper is the study of the adhesion phenomena of bituminous materials and mineral aggregate. The paper describes improvements in the water asphalt preferential test leading to a quantitative measure of the stripping action of water on bituminous films on the mineral filler. It is noted that moisture in the aggregate is detrimental. On the other hand, heated aggregates apparently develop a higher and more permanent adhesion and there are also beneficial effects due to aging of the bituminous mixture.

The emphasis placed upon adhesion phenomena by the Washington Department of Highways is an indication of the increased interest in research of this character. The attention given this problem might suggest the necessity of describing the seemingly erratic behavior of bituminous mixtures in terms of some of the fundamental concepts of physical chemistry. For example, it might be possible to employ a direct quantitative measure of the adhesion tension between the various combinations of mineral aggregate and bituminous materials and use such terms to describe those phenomena of the liquid-solid interface due to variation in physical structure of the asphaltic materials or surface properties of the mineral aggregate.

Mr. Russell of the Wyoming Highway Department describes early experience in that state with bituminous construction and more recent developments resulting from the trial and error method necessarily employed in the absence of any provision for a research program. Several of his observations are of interest in emphasizing difficulties common to other states. High maintenance costs have invariably been associated with narrow, inadequate bases and poor soils with improper drainage. These difficulties are being met by building substantial foundations, removal of the poorest subgrade soils, compacting high fills by wetting and rolling, and eliminating edge failures by the construction of 6-foot shoulders of stabilized gravel.

Mr. Russell discusses briefly the relative merits of medium curing and slow curing oil in noting a trend toward the use of the medium curing cut-backs. The advantages of the latter are given as tougher surfaces with better non-skid properties, less critical asphalt content, and apparently greater durability against stripping action by water. Advantages of the slow curing oils are enumerated as a possible saving of from three to five hundred dollars per mile, a less brittle surface which adjusts itself to normal subgrade movement without cracking, and a surface with better healing properties. It is concluded that SC mats should give good service on adequate bases which are being built today. Mr. Russell also suggests that the excessive hardening of MC asphaltic oils may be corrected by changing the base asphalt or decreasing the mineral filler, and he is of the opinion that both types of materials may find their place where specific conditions favor their use.

In commenting on this paper the writer would like to suggest the use of controlled moisture content and density of fills by methods developed in California as being extremely beneficial and practical. Such definite control tests have been used with considerable success in some Michigan projects. The writer was also interested in Mr. Russell's opinion that highways designed for greater and greater speeds were going out of style. This question appears to be highly debatable. It is true that safety campaigns are emphasizing the desirability for decreased speed as a safety measure, but human nature being what it is, the highway engineer may, for practical purposes, have to contemplate meeting the inevitable demand for higher speeds or face the prospect of being left behind in the march of progress. It seems that speed and more speed is the essence of modern transportation. Increased mechanical efficiency will probably go on and in the writer's opinion it seems scarcely consistent with the trend of the times for the highway engineer to assume that this particular aspect of modern civilization will stand still and, much less, that it will go backward.

Mr. Bollen of the Nebraska Department of Roads and Irrigation has presented a summary of research in bituminous mixtures in that state, listing reports on completed research and projects still in progress. Some of the subjects which have been investigated are:

1. The effect of mineral fillers on stability of bituminous mixtures.
2. Bituminous soil stabilization.
3. Physical changes in asphaltic material after incorporation in the mixture.

Mr. Bollen discusses exposure of the mixture or ''aeration'' as an aid to producing high stability and greater resistance to stripping action of water.

A comprehensive project on bituminous soil stabilization is in progress consisting of 12 miles of stabilized soil base. Both the Bureau of Public Roads and the state are engaged in the preliminary testing and the survey of service behavior. Some very interesting and valuable results may be expected at a later date.

Mr. Finkbiner of the Oregon State Highway Commission describes the development of two types of bituminous surfaces developed in that state which should be of more than local interest. He notes a fact that is rapidly gaining recognition, namely, that stability of a bituminous mixture is not necessarily a function of density but in some cases is produced by interlocking or mechanical arrangement of the mineral aggregate even in mixtures with a relatively high per cent of voids.

Mr. Mason of the Montana State Highway Department has devoted his paper to a discussion of organizations, the aims and activities of which are to correlate research and practice in highway construction, a primary consideration before the present meeting of the Montana Bituminous Conference.

CORRELATION OF RESEARCH, THEORY AND PRACTICE

Discussion

Research, theory and practice may be said to be the cornerstones of engineering accomplishment, or in this case of bituminous road construction. There should be closest interlocking of these three elements for greatest progress and achievement, but the facts are that each activity seems to require a somewhat different type of mind and a somewhat different attitude toward the common objective. Because of this difference in viewpoint it is not uncommon to find the so-called practical man, the one who actually builds the roads, disdainful of the efforts of the research worker who spends his time accumulating data and attempting to translate these data into practical working theories. The practical man sometimes dismisses the product of research by saying it is too complicated and too theoretical. On the other hand, the research worker faced with this situation may become impatient at what he regards the lack of interest and sympathy on the part of the construction engineer and jeopardize the chances of successful co-operation, or he may give up the fight and merely accept the futility of his efforts.

Thus it becomes the first step in correlating research, theory, and practice for the construction engineer and the research engineer to adopt an attitude of sympathetic understanding toward each other and to join hands in a co-operative effort in attacking each other's problems. Inasmuch as the subject of this meeting and the papers presented is to correlate research and practice, it seems of value to define the functions of each and lay the foundation of mutual understanding.

Research is the process of accumulating facts, all the facts, and nothing but facts, assembling and analyzing these data in such a way as to give a true picture of any particular physical phenomenon. Research work must go through several stages as evidenced in the present instance. The first stage of development can be little more than blind experimentation, a more or less aimless accumulation of experience without any well defined problems and only a very general objective in mind. This stage may produce rule-of-thumb methods of procedure, empirical formulae, and considerable skill in practical judgment exercised by the individuals involved. It often produces an attitude of self-sufficiency in those who feel that successful accomplishment worked out under local conditions without an understanding of fundamentals is all that is necessary. Fortunately, it also produces in the minds of those who would achieve greater things a realization of specific problems about which there is a lack of knowledge and which frequently result in costly and disappointing failures in achievement.

Where the proper relationship is maintained the next step comes when the construction engineers seek the aid of fundamental research to get to the bottom of the difficulties that have been encountered. The problems presented to the research worker are generally not easy, else they would have been solved quite readily perhaps in the first stage of development. They are usually complicated by many unknown factors which have to be isolated and measured and finally brought together in a logical description of the complete phenomenon. The search for responsible factors and methods of measuring them may carry the research worker deep into other fields. It may require almost infinite patience and a much longer period of time than the practical man cares to contemplate. Nevertheless such is the true picture of sound research and any permanent solution will not come out of a compromise.

Then finally, perhaps through the brilliant work of some individual secluded in a laboratory or located in the field or through the combined efforts of many, a problem is really solved. The objective, however, is not attained because the solution must yet be translated into terms which may be understood by many in order that new knowledge fulfill a universal service. Herein lies the function of theory, a term which is less understood and more abused than anything of which the writer can think at the moment.

A certain eminent physicist has defined a theory as a group of conceptions in terms of which we describe the results of experience, a description which relates in a logical sequence all the conditions and circumstances which have accompanied the observed event. If the description is complete and accurate it may be anticipated that the recurrence of the same conditions and circumstances will lead to a similar result. Therein lies the usefulness of a theory: It gives ability to predict what will happen under a given set of conditions. In order to regulate physical behavior man can only change the controlling conditions, as otherwise the result is merely a matter of chance.

Such is the fundamental basis of a true theory. A theory is the most practical thing in the world as its sole and only purpose is to translate knowledge for application to practical problems.

Not infrequently one may hear the results of research criticized by so-called practical men as being too theoretical and complicated. Actually a theory may more often be faulty because its basic data are incomplete or erroneous, its conclusions are a misinterpretation of the data, or its simplification has led to the elimination of some of the responsible factors which are actually involved. The research worker is not responsible for the large number of variable factors which nature has placed in certain problems and to attempt to sidestep some of them is not only useless but actually may be one type of dishonesty. The research worker must seek the truth rather than attempt to avoid its consequences.

Then again, some criticism of research must be classified as a defensive reaction on the part of the critic whose mental activity is not equal to the task of discarding some current misconceptions and assimilating new ideas. Such a critic may be likened to the neurotic who has met defeat in some objective in life and, lacking the stamina to attack and master the difficulty, comforts himself by excuses. The neurotic's defense reaction may be poor health, a bad heart, or nervous ailments. The other individual whom the writer has in mind more often blames his weakness on the research worker who is said to be too theoretical.

The purpose of the preceding discussion is to establish in true perspective the situation in which an organziation such as this Conference might hope to promote the correlation of research, theory and practice. Summarizing the theme presented it may be said that research accumulates knowledge, theory translates knowledge, and practice puts knowledge to work.

Research is largely done by individuals in the laboratory or field. Practice is carried out in the field usually under the pressure of getting things done which does not allow time for great deliberation. Theory may be formulated largely by individuals in the seclusion of their study but certainly is never complete until it has been thoroughly checked and rechecked by both research worker and construction engineer in actual practice and by a frequent interchange of opinions.

It is in bringing together the component parts of the enterprise that an organization such as this may perform a useful function. Knowledge gained by a few must be disseminated to many. Every opportunity to meet for discussion of mutual problems cannot help but benefit all active contributors. Such an organization, if it does no more than encourage research and promote better practice, will have established itself as a potent factor in its particular field of endeavor.

Conference on Research Correlation.

CHAIRMAN, R. N. TRAXLER
The Barber Asphalt Company
Maurer, N. J.

Conference Board

BAILEY TREMPER, Materials Engineer
Washington Department of Highways
Olympia, Washington

CARL R. REID, Materials Engineer
Oklahoma State Highway Commission
Oklahoma City, Oklahoma

RAYMOND HARSCH, Asphalt Department
Shell Oil Company
San Francisco, California

EMBY KAYE, Vice-President
Skelly Oil Company
Tulsa, Oklahoma

T. R. CORBETT, Chief Chemist
Yale Oil Corporation
Billings, Montana

Mr. Traxler: As practical bituminous construction engineers what do you think can be done toward the correlation of research work being done in the various states?

Mr. Harsch:
California

I think there is probably no better co-ordinating agency than the Bureau of Public Roads. Having been associated with them and with the state, I think one of the easiest solutions of this problem would be the utilization of the materials engineers of the Bureau of Public Roads in correlating the research that is done in the states under their jurisdiction. For instance, the Portland office of the Bureau has three states—Oregon, Washington and Montana. Mr. Benedict undoubtedly transfers information from Washington and Oregon to Montana and vice versa, as to what is being done in this area. The same thing applies to Arizona, California and Nevada. But there is lack of correlation between areas, as between the Oregon, Washington and Montana and the California, Nevada and Arizona groups. It is my thought that there is possibly a chance of getting the materials engineers of the Bureau to report their information to either a central committee in the Bureau or circularize it between their various districts, and in this way all of the states will benefit by their information.

Mr. Traxler: It may be that someone from the Bureau of Public Roads has something to say.

Mr. Benedict:
Bureau of
Public Roads

I might say by way of general information—although it is hardly within my province to distribute information that probably should come from our Washington, D. C., or regional Offices—that such a move as Mr. Harsch suggests has already been begun. Each Bureau district has been instructed to prepare an annual report outlining the unusual features of construction and research in that district. It is uncertain, of course, just what use will be made of the reports. The present plan is merely to use them for disseminating information, construction experiences and suggestions within our own organization. Any distribution outside of the organization must, of course, be previously authorized by our Washington Office.

Mr. Traxler: Do the Materials Engineers of the various states have something to say about what could be done concerning the interchange of ideas and correlation of the work that is being done?

Mr. Tremper:
Washington

I believe that what Mr. Harsch has brought out is worthy of a good deal of thought. It would be immensely valuable to every state to know what the problems are in other states, how they are being attacked, and what success they are having in solving them. And I believe if this Conference in some way would contact the Bureau officials in Washington, expressing the wish that the information picked up by the various district engineers of the Bureau be summarized and made available to each state, it would be a very great gain for all concerned.

Mr. Houk:
Alabama

I believe the great essential in correlating the information in different states and finding out what other states are doing is to send one or more individuals from your organization to the different states at the proper time—one of the best times would be after the spring break-up—to see what other states are doing. Send them around several times during the year to visit the other departments. The problems of bituminous construction really, after all, have very much in common. They vary of course with the weather, soil, and climatic conditions, but a great many problems are common to all states, and the quicker we acquire information as to how the other fellow solved or failed to solve his problems, the quicker we will solve our own.

Mr. Traxler: Personal contact certainly is the best way to obtain correlation. No matter what agency does the correlation, that accomplished by personal contact will be the most satisfactory.

Mr. Krchma:
Missouri
Wouldn't it be more economical and better to have groups assemble occasionally and meet each other individually than have them all together. You would have probably three different meetings between two individuals rather than one meeting between a group of individuals. It might not be as practical, but it would be better. It would be more expensive and more elaborate, but any contact is going to be valuable in the interchange and correlation of ideas.

Prof. Lang:
Minnesota
It seems to me that in addition to the Bureau of Public Roads acting as a clearing house for your research problems, they might go still farther and co-ordinate various highway departments and materials laboratories so as to carry out definite lines of research, even going so far as to suggest assignments so that there will be less overlapping. We might get something very definite in that way, I believe.

Mr. Traxler: Any reactions to that idea?

Mr. Shumate:
Colorado
In the correlation of this information I think it would be well to consider the geographic locations of the districts and to avoid the possibility of this voluminous bituminous correspondence that we discussed a while ago. As for instance, in Colorado, Montana, Wyoming, New Mexico, and Idaho, probably their problems are almost identical, or very nearly so. Problems of men in Alabama and Mississippi necessarily won't affect us of the Rocky Mountain region, while our problems would not affect them. They would not be interested in our problems because the same situations would never exist there, and in working through the Bureau of Public Roads for this information,

if it could be handled by districts which are common to each other, it would be quite a help, I think.

Mr. Traxler: The feeling at the committee meeting last night was that correlations should be worked out in regional groups of three to five states having a common interest.

Mr. Houk:
Alabama

It is true that we have certain group problems, but we have not yet in many states solved the problems common to every state. I think we should first learn the fundamentals and then later go after those problems of lesser importancee that are only common to groups. There are certainly many group problems, but it is my observation after traveling the greater part of the United States in the last year that many of the problems that have not yet been solved are fundamental and common to all states.

Mr. Krchma:
Missouri

Wouldn't it be the purpose of the committee, which would be made up of representatives from each of these states, to handle such fundamental problems?

Mr. Traxler The committee believes that the group should not necessarily limit themselves to group problems. The general problems might be handled most effectively through personal contact.

Mr. Benedict:
Bureau of
Public Roads

I should like to express concurrence in Mr. Houk's remarks. It is true that there are problems confined to certain individual groups, but it is also true that there are fundamental problems common to us all. It is very notable in reviewing the papers for this Conference that, under similar conditions and circumstances, conclusions by some engineers are contradicted by others. It seems that an exchange of experiences and ideas would bring about the selection of the best points of each of these opinions.

Mr. Traxler: Does anyone else have ideas as to how this correlation could best be done?

Mr. Krchma: Missouri

I wonder if I made myself clear when I referred to the general committee. The general committee would be one which would have representatives from each section; that is, groups of three to five states would have representatives meet with representatives from other groups of states. To form this general committee, I imagine it would be far more economical and not so unwieldy to have small groups of representatives from various groups of states meet than have an individual from each state visit around. Some are able to do it, but I wonder if it can be generally done.

Mr. Hveem: California

I think it would be well to clarify whether we mean correlation or research or correlation of research activities. The results might be correlated, and the information dispensed, but I think we should not assume that the same sort of correlation is going to be entirely effective in the allotting of research projects.

Mr. Traxler: Also, you cannot dictate to anyone as to what research work he will undertake, and it is quite a problem if you attempt to outline programs. We should only try to bring together the information that is being obtained and to prevent duplication where possible.

Mr. Krchma: Missouri

I doubt if it would be the entire purpose of these groups to discuss research. I think they have numerous mutual problems on which they never intended to do research, but which discussion would offer some solution. It would never do to dictate to various individuals what they should research on, but I do believe it would be of considerable benefit to discuss mutual fundamental questions on the work being done.

Mr. Traxler: Discussion of mutual problems whether they concern bituminous research or life in general is most valuable and stimulating. If several people have the same problem and talk it over, great benefit is derived by all those involved. Is there anything further?

Mr. Wood:
Texas

I would also like to consider the thought, is it desirable to eliminate duplication of research? We do quite a lot of work that we believe would be barely applicable to the other states but very important in our own organization. I would suggest that it would be desirable to have a group meeting of material engineers who are interested in research work from the states immediately in the vicinity of your own state. Many of our projects are research projects. I don't think it is possible for anyone to be able to tell just exactly what we would like to know. Quite often duplication is of great benefit then. I don't think you can get a raise out of a group meeting. You have to contact the members individually and off the record to learn anything. In relation to this subject, I find myself out on a limb, but when I look about, I find every other limb of the tree occupied; I am not alone.

Mr. Traxler: We must admit there is a great deal of truth in what Mr. Wood has said. If there is no further discussion, I wish to call your attention to the suggestions that your committee has offered.

Do you care to take any action on the suggestions made by Mr. Housel's committee?

Unidentified Gentleman: It might be in order to suggest that the proposal be put forth as your committee suggests, but I think Mr. Wood's statement ought to be considered. I think we could well leave out the recommendations of the committee as to the elimination of duplication. I think that would be for the committee to decide.

Mr. Traxler: You think "in order to eliminate duplication" should be struck off?

Unidentified Gentleman: That should be left to the discretion of the committee and their chairman.

Mr. Nevitt: Missouri I don't think that the term ''duplication'' should be taken too literally. Often research work consists of two or three organizations of men heading toward the same objective and exchanging the same ideas. I contact quite a number of highway departments, and I know that there is a great deal of wasted effort. A lot of these ''half-baked'' things Mr. Woods talked about are being done, not for the reason he gave necessarily, but because after they have gone half way they find someone else is working on the same thing, not complementary work but identical work, purely duplication with no benefit to either department. It may be that both of these states could have advantageously worked on the same problem, not necessarily jointly but not following in each other's footsteps, and not duplicating a lot of effort. That is not only true of the states but of the petroleum industries as a whole. There is often purely a duplication of laboratory work. The particular presentation might be different, but the laboratory work is not different. I think the whole idea is not to definitely say that only one state should work on one thing, but to see that they should intelligently know what other states are working on. I think the tacit purpose we are trying to reach is to know what the other fellow is doing and not to control his work or prevent him from doing it. I think there is a distinction which should be kept in mind.

Mr. Chamberlain: Bureau of Public Roads I think the function of the committee should include the encouragement of new research problems. In other words, there are many research subjects on which we need additional information which are not being investigated. I think the committee could very well correlate and initiate such projects.

Mr. Nevitt:
Missouri

One thing I think should very carefully be noted by the group. This committee doesn't organize these group committees. It merely is given the authority of the Conference to try to encourage some such organization. In other words, the committee is more or less told, if the Conference likes the idea, to try to organize the people who are functioning in that line and give them your encouragement to go ahead and do something if the need is really there.

Mr. Krchma:
Missouri

We are simply suggesting that the Conference form a committee to deal with organizations that are already established—State Highway Official's organization or any organization—to accomplish this work.

Mr. Benedict:
Bureau of
Public Roads

Mr. Chairman, that work is largely covered at present by the Highway Research Board. We are talking about doing something that is already being done.

Mr. Traxler:

Well, I suppose to a certain extent, but apparently not to the extent that the practical men in many of these states would desire.

Mr. Krchma:
Missouri

I believe this was covered in the committee discussion last night and it was our opinion that this would be something to supplement the work done by the Highway Research Board and eventually taken over by the Highway Research Board, if it isn't already a part of the Highway Research Board. The committee on which Mr. Reagel is acting will eventually, when it gets fully underway, cover most of the work being done by the various states. If these questionnaires are filled out carefully, the current research work being done by the various states will be covered by the Highway Officials' Index, which Mr. Reagel discussed under bibliography. But it does appear that this would be an excellent opportunity for two or three members directly responsible for research in the highway departments to get together and discuss their research. I personally think these meetings are desirable. It would give the research and materials engineers an opportunity to discuss their work first-hand.

There is no doubt but that the Highway Research Board will eventually do what the Conference is discussing, but the immediate need should be filled. The work of the Highway Research Board in this respect will be eventually far better, but isn't functioning as yet. Mr. Reagel's index will be out sometime this winter and will be the committee's first effort; none the less, it will be sometime before they are fully functioning and we would like to suggest something supplementing their efforts until that time.

Mr. Traxler: Any further discussion?

Mr. Hveem:
California

That thought is rather new. I have a rather loosely associated idea which may not be in order at all. It seems to me that the idea of this committee is an excellent one, but I think it is not the research and materials men who need encouragement to get together. I think the obstruction is a financial one. I believe that the thing which a group of this sort might possibly do is to offer some resolution or recommendation to those members of highway departments who control the purse strings, to permit their materials engineers to get together at more frequent intervals if it is possible, and I believe it would be. Materials engineers do not require encouragement or additional incentives to get together to discuss research matters and things of mutual interest, and I believe that the committee could direct their efforts to provide ways and means, taking whatever steps they may find necessary without our setting forth the details. Many administrative departments are not altogether clear as to just what is accomplished by meetings and conventions such as this and there is a certain amount of feeling that out-of-state meetings are in the nature of a vacation trip or something of the sort. It is my opinion that a committee definitely instructed along these lines might go a long way in solving what is really the problem.

Mr. Traxler: It was the thought of the committee in making this suggestion that we would get established agencies or organizations to develop some such discussion. A committee from the Montana Bituminous Conference would approach those agencies to see if something could be done toward getting the materials engineers together. Our time is drawing to a close. Do you want to do anything about this suggestion?

Mr. Benedict: Bureau of Public Roads
Mr. Chairman, there have been a great many different opinions expressed. I should like to make a suggestion that the committee working on the correlation of research prepare resolutions and present them at the end of the general meetings. These resolutions should coordinate and put into concise form the comments and suggestions that have been made.

Mr. Traxler: Any discussion concerning Mr. Benedict's suggestion?

Mr. Nevitt: Missouri
Mr. Chairman, I would think that the recommendation of the committee is essentially that. It may not be essentially the wording but as I get it that resolution is to give to this committee on correlation of research the opinion of the Conference that research should be accomplished and various authorities should be approached on methods and to show how this might be accomplished.

Mr. Traxler: We do not want to complicate this situation by going into detail about how correlation should be accomplished. It would be much better for the committee, if you wish to establish one, to approach the various agencies now established and find out from them the best method of procedure. Your present committee fully expected the Bituminous Conference to work through some other agency such as the A.A.S.H.O., Bureau of Public Roads, Highway Research Board, Asphalt Institute, etc.

Mr. Benedict: Bureau of Public Roads — Mr. Chairman, may I put my suggestion in the form of a resolution that the majority sentiments and opinions that have been expressed by this group be reduced by the committee on correlation of research to a concise, co-ordinated plan of action.

Mr. Nevitt: Missouri — If Mr. Benedict's suggestion is a resolution, which is more or less what the committee has recommended, if it can be taken as such, I will be glad to have a second.

Mr. Traxler: You want to present that? If you would like to, discuss that plan.

Mr. Benedict: Bureau of Public Roads — The committee should draw up a resolution which they feel embodies the sentiment of this group and present it at the conclusion of the scheduled meetings so that we might concur in it if we wish.

Mr. Traxler: Is there any discussion concerning Mr. Benedict's resolution? All in favor say aye. Those opposed? The motion is carried. It will be the duty of the committee on correlation of research and bibliography to present to the Conference on Thursday morning a set of specifications as to just how this work on correlation can be accomplished. Is there anything else anyone has to say before we adjourn? I want to thank you very much for your cooperation with and interest in the work of the committee.

Papers Prepared

on

Research Correlation and the Development

of a

Bituminous Bibliography

for

The Montana National Bituminous Conference

1937

The Correlation of Bituminous Research and the Need for a Bituminous Bibliography.

By

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There has been a long felt need for an agency or organization to provide for a clearing house for low cost bituminous highway construction, research activities, research correlation, information, and for the establishment and continuance of a comprehensive bibliography treating all phases of highway bituminous construction.

At the present time, there are a number of organizations whose activities have produced a wealth of information. Yet, none of these incorporates all of the features mentioned above. For illustrative purposes it will be necessary to review several of these organizations together with their aims and objectives.

In December, 1914, an organization was formed which is now known as the American Association of State Highway Officials. The purposes of the organization, as set forth in its constitution, are to "study the various materials, methods of construction and maintenance, and other highway problems of the United States; to exchange ideas; to promote a closer relationship between state highway departments with a view of establishing uniform system of administration, construction and maintenance, and legislation for the purpose of conserving the capital invested in highway construction and maintenance by producing the highest possible efficiency; and to co-operate in every way possible with the United States Office of Public Roads or similar federal organization in the consideration of road problems."

This organization's publications consist of "Specifications for Highway Materials and Methods of Sampling and Testing," and "Report of Committee on Highway Research Activities."

The American Society for Testing Materials was incorporated in 1902. Its purpose is "the promotion of knowledge of the materials of engineering and the standardization of specifications and the methods of testing." The publications issued by the society are: ''Proceedings, Book of A.S.T.M. Standards, Index to A.S.T.M. Standard and Tentative Standards, Book of A.S.T.M. Tentative Standards, A.S.T.M. Bulletin, Year Book, and Preprints.''

In the field of highway research activities, the Highway Research Board of the National Research Council is probably the most outstanding.

''The purpose of the Highway Research Board is to provide a national clearing house for highway research activities and information.

''In its practical workings the functions of the Board have been: To provide a forum for the discussion and publication of the results obtained by individual research workers; to organize committees of experts to plan and suggest research work and to study and correlate results; to publish and disseminate research information; to provide a research information service; and to carry on fact-finding investigations when special funds are available.

''The Board is organized as a project of the Division of Engineering and Industrial Research of the National Research Council. * * *

''Much of the technical work is done by committees of specialists and recognized authorities which are organized under seven departments: Administration and Finance, Highway Transportation Economics, Design, Materials and Construction, Maintenance, Traffic, and Soils Investigations. * * *

''Regular contacts are maintained with all state highway departments, with the engineering colleges and with many city engineering departments, through regularly appointed contact men.''

The papers and reports presented at the annual meetings of the Highway Research Board, having value as reference material, are published each year in the Proceedings. In addition to the Proceedings there is issued ten times a year ''Highway Research Abstracts'' for the purpose of disseminating information about valuable unpublished research work, or that which is published in foreign journals or other media not widely distributed in the United States.

The Asphalt Institute is an organization sponsored by various oil companies. The purposes of the Institute are for the development of asphalt technology, research on asphaltic materials, and the publication and distribution of asphaltic literature.

Worthy of special note is the Institute's latest publication, a bulletin entitled "The Asphalt Forum." This bulletin proposes to act as a "clearing house for administrators, designers, constructors, teachers and researchers of the West. It is to be a facility for exchanging ideas, explaining designs and methods, reporting research in progress and recording current literature."

This piece of work is considered an important step in the right direction. The only criticism to be offered is that "The Asphalt Forum" does not cover the entire field of bituminous highway construction and the bibliography covers only asphalt and its uses, compiled from current periodicals and proceedings.

With the foregoing review in mind, it is possible to proceed with a discussion on research correlation and development of a bituminous bibliography. However, it must be borne in mind that any action taken along these lines must be both of value and of interest to producers, consumers and parties interested in asphaltic materials insofar as they pertain to bituminous highway construction.

The first point for consideration is the organization and financing of an agency to carry out the proposed program. The membership should be composed only of those who are vitally interested in the development of the project. This would include consumers of materials, producers of materials and a general interest group.

Financing can be accomplished through the contribution of annual dues which entitles the member to receive all publications produced by the agency. Extra copies of publications at special prices would be available to members. It would also be a decided advantage to limit the distribution of publications to members, thereby eliminating subscriptions to publications by nonmembers at lower rates.

The most urgent need at the present time is the development of a bibliography which will cover all phases of low cost bituminous highway construction, and this should be given first consideration.

The bibliography must not only be comprehensive but must also be impartial to trade differences. This is particularly true in the case of soil stabilization where the desired effect is produced either by physical or chemical methods, that is, through the use of materials other than bituminous products.

It is realized that the development of a bibliography is a large undertaking. The most difficult task would be the searching out of old material. Furthermore, it must be remembered that the older writings are now more or less obsolete and later articles contain more information. Yet the old material cannot be discarded as it is of historical value to the older and possibly more thorough research workers.

No doubt, a good many members have available in their files, bibliographies which, at some time or another, they have deemed necessary to compile. By submitting these to the clearing house for segregation, the proposed bibliography could get off to a good early start.

It is suggested that the bibliography be subdivided into two parts: Part One, to include books; Part Two, to include articles found in periodicals.

Beyond a doubt, the bulk of material available is to be found in the various periodicals. These include the various trade magazines, journals, conference proceedings, government publications and bulletins, trade literature and others. Furthermore, this bibliography is not to be limited to material published in this country but must also include subject matter from foreign literature.

The bibliography should be listed under departments and then arranged under subject headings. Perhaps the best listing of departments is that outlined by the Highway Research Board, which is as follows: Administration and Finance, Highway Transportation Economics, Design, Materials and Tests, Construction, Maintenance, Traffic, and Soils Investigations.

It is suggested that the bibliography be arranged in both subject matter and author indexes. The subject index should contain the title of the article, author's name, complete reference, and a brief abstract of the article under discussion. The author's index should contain the name of the author and the title of the article.

Until such a time as the bibliography could be brought up to date, it would be necessary for the agency to make assignments to members for the abstraction and compilation of old material. The agency would have to conduct a survey of the library facilities of its members to determine whether or not they have complete volumes of the various periodicals and conference proceedings prior to the making of assignments. The ultimate success of the bibliography, therefore, is wholly dependent upon the co-operation received from the members.

The efforts of the agency should be concentrated upon the bibliography until such a time as the bibliography can be brought up to date. Then, and not until then should it consider expanding into other channels in its publications.

It is hoped that the progress will advance rapidly enough to permit the publcation of the bibliography quarterly. Once it is brought up to date, it should be published monthly, as current literature can be quite readily abstracted.

It is suggested that the current abstracting be done on a cooperative basis. This could be accomplished by assigning each member one or two periodicals for abstracting. In this way the burden would not fall on a few members but would be more uniformly distributed throughout the agency.

Mention has already been made of expansion. This point should now be given some consideration. In the review of the organization now in existence, an effort has been made to outline their aims and objectives. It is readily seen that all have not fully attained the end to which they had aspired at the time of their organization.

The purpose of the proposed agency is not an attempt to replace existing organizations but merely to supplement to highway construction information insofar as it pertains to low cost bituminous highway construction and maintenance.

By the very nature of the proposed agency, it would automatically become a clearing house. The monthly bibliography publication could be expanded to include current topics and problems. A section could be devoted to research and technology, not in the form of comprehensive treatises, but rather in the form of news items. This would serve as a source of information to the various members as to what is going on in the laboratories of its members, what research work is in progress and what research is proposed.

Another section should be devoted to materials testing methods, insofar as they are applicable to bituminous highway construction. This would afford a forum for the discussion of test methods now in use but which have not been accepted and promulgated by such organizations as the American Society for Testing Materials, Federal Specifications, American Association of State Highway Officials, and others. Frequently, when test methods of this type are put into use, inconsistencies are found either in the test procedure itself or in the test results. This has brought about modifications of the original test method to the extent that if several laboratories were to work a specified sample on a co-operative basis, the results of the tests would not be in agreement. The forum would provide a medium for the discussion of the relative merits and weaknesses of a given test method with a combined effort to remedy the inconsistencies.

It is hoped that this paper contains some helpful suggestions to attain the end for which it is intended.

A Correlation of Research to Practice in Bituminous Surfacing.

By

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In the belief that two recent developments in the bituminous practice of Oregon might be of more than local interest, their evolution and use will be described. They are: "The Cutback Asphalt Wearing Surface" and "The Road Mix Using RC-3 Cutback Asphalt."

CUTBACK ASPHALT WEARING SURFACE
(Plant Mix)

It has been a universally accepted belief in times past that the only successful bituminous pavement was composed of that asphalt mixture which had the greatest possible density with the least possible amount of voids. This is still true in the so-called tight bituminous mixes. However, there has developed a belief in another type of mixture, known as the open mix, which does not depend on density for stability, but upon a grading so proportioned that stability is obtained by a close interlocking of the mineral aggregates. We believe it to be true that either a quite open or a tightly closed mix should be used, since danger from freezing is much increased in a semi-tight mix which contains insufficient outlets for the expansion of the water in forming ice. The greatest incentive to the development of an open mix has been the necessity of producing a bituminous wearing surface with the ability to remain practically skid proof over a period of years.

In that period before the advent of the rubber tired vehicle it was customary to lay a sheet asphalt mixture consisting of sand, asphalt, and filler. This generally was placed on a concrete base and was quite expensive. Following this came the various types of bituminous concrete, all, however, being rich in asphalt to withstand steel shod traffic. At the change in the type of traffic from steel to rubber the large amount of asphaltic cement became unnecessary and was accordingly reduced from an average of about 7.5% to about 5%. Then the speed of vehicles entered as a vital factor. Various methods of laying a surface which would be more or less resistant to slippage came into vogue. Oregon adopted a coated chip procedure, which is simply imbedding ¾″ to ¼″ crushed material, coated with about 2% of asphaltic cement, into the road surface after "breaking down" the bituminous concrete by one rolling.

In seeking a nonskid wearing surface various mixtures were not only made up in the laboratory, but, with the co-operation of our maintenance department, were laid as patches on several heavily traveled roads. Although all of these open mixtures were successfully placed on the road using 95-plus oil, E and D grade asphalts, and RC-3 and RC-4 cutback asphalts, it was felt that probably the safest and most satisfactory was an RC-4 binder with the following graded mineral aggregate:

Passing ¾″ and retained on ¼″	45%-55%
Passing ¼″ and retained on #10	30%-36%
Passing #10 and retained on #200	8%-14%
Passing #200	0%- 2%
RC-4 cutback asphalt	4%- 6%

Experience has proven that keeping the filler as low as possible tends to prevent the balling up of the RC-4, and thus eliminates a great deal of trouble with the mechanical spreaders.

A much better mix is obtained by permitting none of the material between the #10 and #200 sieves to be natural sand. This can be economically done since such a large percentage of ¼″-#10 mesh material is used, thus leaving the #10-#200 mesh material from the ¼″ minus for this purpose.

A cover coat of hot #10-#200 mesh material generally coated with from ½% to 2% of RC-4 is swept sparingly across the roadway to slightly seal the surface. Especially is this necessary in towns. The browning with RC-4 kills the objectionable dust.

It is believed that a paving mixture as above described will give many years of skid free service.

ROAD MIX USING RC-3 CUTBACK ASPHALT

Road mix, using RC-3 cutback asphalt as the binding medium, evolved from the necessity of giving to sparsely populated regions surcease from the interminable clouds of dust which are raised by rubber tired traffic from the rock or gravel surfaced roads. At first it was thought sufficient to merely kill the dust with a light shot of 50%-60% asphalt of 80 penetration. This method was shortlived, however, since it was found that the dust from the road sometimes blended with the oil to make a fairly satisfactory mixture, but sometimes the outcome was far from satisfactory. Since a certain amount of mineral matter matted with the oil, the idea was conceived to regulate the amount of oil placed and control, insofar as possible, the material to be mixed with the oil. Scarification of the surface of the road was resorted to, with or without the addition of size controlled aggregate, and the binder used was a 60%-70% asphaltic oil at 80 penetration.

This was quite difficult to stabilize since the fluidity of the binding medium had to be controlled entirely by the correct percentage of filler; but when so designed gave satisfactory service. The difficulty of finding a suitable filler and insuring its even distribution in the aggregate led to the use of controlled material and the abandoning of SC-2 road oil and adoption of RC-3 cutback asphalt.

At the present time a pit run material with or without the addition of fines is deposited upon the prime coat at a very definitely controlled quantity per station, usually from 18 to 22 cubic yards. This material is shot with RC-3, usually at night, and mixed the following morning. The aggregate is constantly checked with screens and sieves as the materials are delivered on the road to insure that they meet definite grading characteristics previously determined upon by the laboratory from a thorough preliminary examination of the pit.

The best results in a bituminous mixture are obtained from the use of the hardest possible asphalt which can be manipulated under specific conditions, and which is able to withstand the minimum temperatures of the locality without becoming too brittle. With careful handling RC-3 can be very successfully used in a road mix with advantage. Since the asphaltic residue remaining in the pavement after volatilization of the solvent is quite stable, there is no necessity of having a large percentage of filler present. The rate of setting is so much more rapid than with the MC binders, that in approximately three days' time the seal coat may be applied.

Progress in Research Plans and Correlation of Research in Bituminous Construction

By

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The engineer, charged with the responsibility of constructing highways, must, of necessity, take cognizance of these fundamental principles—ability of the highway to adequately support the loads to be expected without excessive maintenance costs and the safety of those who are to use the highways.

Almost invariably, when an entirely new piece of equipment is placed on the market for use, a number of so-called "bugs" develop and it is necessary to make changes and improvements to bring about the desired results. Even with most careful design the machine seldom lives up to expectation, many weak points being discovered through actual operation. And so it is with our highways—failures exposing inadequate design or lack of knowledge of the materials entering into the construction are constantly arising to harass the engineer.

To avoid such failures through overdesign is costly beyond any justification. Thus it is apparent that, in so far as possible, systematic research precede actual construction, and likewise it is just as important that results be checked against the research findings to such an extent that the two are so closely associated as to eventually result in as near perfect accomplishment of the purpose at hand as possible and at costs that are commensurate.

With the constant demand for more mileage and the improvement of now inadequate highways, funds for research are necessarily held at a minimum and it is, unfortunately, not always possible to develop, through research, a definite background upon which to base our design. It therefore becomes encumbent upon our engineers to develop such a background through trial and error on actual construction. Such has been largely the case as regards bituminous construction in our state. I shall therefore briefly outline our experiences and attempt to show what has been done to correct our earlier failures.

Our first experiment in the use of oil as a binding medium was a decided failure due to the type of oil used. While records are not available at present, there is little doubt that it was a paraffin base oil and failed completely to bind up the aggregate. The surface broke up and potted so badly that it was necessary to rework it until it had to all purposes reverted to its original condition as a gravel surface.

A first-hand inspection was then made of oiling work being done in California and as a result some California road oil was shipped into the state for our earlier oiling projects. Realizing the possibilities before them, our own state refineries immediately took an active interest in the development of a suitable oil. From the time of these first projects until 1933 all oil used was of the slow curing type. Low viscosities and asphalt contents of approximately 60% were used exclusively due to the erroneous impression that high viscosity oils could not be successfully processed with the equipment then in use. Experience soon taught us, however, that higher viscosities with correspondingly higher asphalt content, could be readily processed and specifications for the oil were drawn accordingly. Plant mixing of the oil and aggregate had by then been established and a special oil was set up for this type of work which called for viscosities of 1100 to 1400 and an asphalt content of not less than 75%. A recent inspection of many of these projects show them to be in excellent condition at this date with whatever failures that are evident, caused from some reasons other than the type, grade or character of oil used.

As interest in bituminous surface construction gained headway throughout the country and particularly in the Rocky

Mountain and Western states it became more and more evident that specifications must necessarily be set up which would completely cover the field so far as needs were concerned and which would be uniform in themselves. This was accomplished through the co-operation of the Bureau of Public Roads and the Asphalt Institute working in conjunction with the highway testing departments. Thus, except for slight variations, specifications were adopted covering slow curing or residual oils, medium curing or kerosene cutback asphalts, and rapid curing or naphtha cutback asphalts.

Since the adoption of these specifications there has been a gradual swing from slow curing residual oils to the cutback asphalts with the medium curing taking the place of first importance. Such has been the case in our state and for the past two years practically all bituminous surface construction has utilized MC-1 for prime coat, MC-3 for mixing and RC-2 for sealing the surface.

From the very first successful oiling project, this type of construction was warmly received by the public. As a result, a bond issue was provided and those in authority were more or less obligated to provide dustless, smooth riding roads throughout the state. In order to accomplish this and satisfy the public until such time as more funds were available it was necessary to carry out a program of thin mat construction many of which were placed on projects that were not in proper shape to receive this type of surface. Results, even under these conditions, were surprising and in some instances these roads are still carrying heavy traffic.

With the public temporarily satisfied, opportunity was afforded to give careful consideration and study to a general program of reconstruction. From the standpoint of building safety into our highways it would seem that we have no longer to look to the future so far as vehicle speeds are concerned. The cry now is to reduce speeds and in the face of that it is not at all likely that they will be increased. Such being the case our present standards of 36′ foot widths with 1000′ foot sight distances on our more important roads should be adequate. Careful consideration is likewise being given to alignment and with oil paved surfaces of 24 foot with 6 foot well compacted shoulders of gravel on each side and slopes of five to one wherever possible the roads should present but little hazard to anyone competent to use them.

Careful studies of surfaces that have been built in the past has of course led the way to our present designs. High maintenance costs have invariably been associated with narrow widths, inadequate bases and poor soils with improper drainage. Steps are being taken to correct the conditions on all present construction by building substantial foundations from the ground up. Decidedly bad soils such as heavy clays and bentonite are removed completely and backfilled with suitable material. High fills are compacted by wetting and rolling. Heavy bases of pit run gravel properly bound with suitable binders by watering, processing and rolling are adding much to stability of our foundations. A leveling course of well compacted crushed gravel gives an excellent base on which to lay the final mat or wearing course. The additional support furnished the mat by the six-foot gravel shoulders and the five-to-one slope put to an end the failures which formerly occurred at the edges of the oil mat.

Careful investigation has convinced us that very few failures of the surface mat can be attributed directly to the type or grade of oil or the method of construction. Rather are the failures caused through inadequate support. Attention has therefore been centered on more substantial bases and wider sections.

Analysis of soil conditions are made and decidedly unsuitable soils are eliminated. On those sections where soil is not good and still not bad enough to be removed the grade is strengthened by increasing the base course with pit run gravel. In most cases of this kind a leveling course of gravel crushed to 1″ or ¾″ is placed on the pit run base and the mat is placed above this. Base courses have been extended to cover the entire surface from shoulder to shoulder thus increasing the support at the point where most failures have occurred in the mat—namely the mat edge.

Grading analysis of pit run materials are made and recommendations made to the plans department to cover special provisions for each project as to permissable grading of the aggregates. Cementing value tests are likewise made on the fine or minus 10 mesh portions and recommendations made as to the necessity of binder and if needed the amount to be used with material from each pit on the project. A cementing value of 250 pounds per square inch on specimens of the minus 10 mesh, moulded in a plastic condition and dried thoroughly before testing, has tentatively been established as a minimum. In case the minus 10 fraction of the gravel fails to meet the above requirement binders are added in such amounts as necessary to produce a satisfactory cementing value. In constructive bases water is added, the material processed with blades spread and thoroughly compacted by rolling. Where the base or leveling course is to be followed closely with an oiled mat binder is held to a minimum so as not to have any more clay than necessary adjacent to the mat. By closely following laboratory recommendations toward the grading and binders and the established methods of construction excellent bases on which to place the mat have been provided.

As previously stated, we have made a very decided change as to the use of MC-3 grade of cutback for all mat construction. Recent inspections have however convinced us that we have not altogether been justified in this procedure. Many excellent projects have been built in the past with SC-3 oils and under conditions which are not at all comparable with present standards insofar as widths and stabilized foundations are concerned.

Mats constructed with MC-3 cutbacks present a tougher surface and one which has much better nonskid properties. They are not so critical as regards the correct proportioning of oil and aggregate and successful results may be obtained with a wider variance in aggregate grading than is possible with SC oils. MC-3 mats are not, apparently, so greatly affected by water.

On the other hand more MC-3 is required with the same aggregate than SC and the cost per gallon is higher. From three to five hundred dollars per mile can be saved through the use of SC in place of MC. While MC mats are decidedly tougher they also are decidedly more brittle and tend to crack on the slightest movement of the base. Cracks which thus develop do not have the ability to heal themselves as in the case of SC mats. There are, of course, possibilities of correcting this condition and two methods suggest themselves, —use of less fines with this grade of oil and changing the base asphalt, from which the cutback is made, to a higher penetration material. We expect to give these points consideration on future work and hope to have some information to report at a later date.

On the basis of information and experience which we now have it is proposed on future work to decide on the grade of oil to be used from a careful study of all conditions which might affect the final success of the project. For the present, at least, MC-3 will be used on all first class roads. On all other roads where drainage conditions are satisfactory and the aggregate for the mat is of a type and grading suitable for SC oil this type will be specified. Since, even under more or less unfavorable conditions, SC mats have given excellent service the only conclusion that can be drawn is that we should expect very few failures when placed on the substantial foundations and bases which we are today building. Lean and rich spots in the past have been noticable in SC mats as has been excessive rolling. This condition can however be eliminated through careful control of aggregate gradings and since in most cases the application of oil and mixing is done with traveling plants a more careful control of oil application is possible than was the case in the past.

The saving effected in the use of SC-3 over MC-3 can be used to place a stone chip seal coat which should result in a further saving in that it will not have to be replaced as often as the present paint seal which is applied to all surfaces.

Design of mixes for all mats are made in the central laboratory. Preliminary samples of pits to be used are crushed, grading analysis made and oil mixtures established. Formulas for the purpose of arriving at the correct amount of oil to be used have been abandoned entirely and the personal judgment of the operator substituted. While this may seem a rather hit or miss method of control we have found that successful results have been accomplished with a minimum of over or under runs on actual construction. Data thus established relative to percentage and grade of oil to use as well as quality and amount of binder to be used in the base courses is furnished to the plans department where estimates for each project are set up in accordance with the laboratory recommendations.

Stability tests as well as tests which are intended to show the suitability of the fines, such as the swell test, seem to be relied upon by some states to a great extent. Doubtless these tests have value and should have a definite place in the acceptance or rejection of materials for mat construction. We are, at the present, making arrangements to include a series of such tests to determine for ourselves whether or not they are justified. Many of the states have likewise introduced special clauses in their specifications for oils and cutbacks. A notable example of this is the Oliensis Spot Test. While some sections of the country, due to the nature of the crude supply, may find such a test requirement to be of decided importance, we do not seem to be so affected. In fact we have an outstanding example which definitely places such a test in the position of being a disadvantage rather than an advantage. On one particular section of oiled surface the oil used would have failed decidedly on the basis of the Oliensis test and yet that section has given us first class service. Careful consideration must therefore be given before limiting clauses are introduced into a specification, lest they act as boomerangs.

While the design of oil surfaces is a direct function of the laboratory the actual field or construction work is supervised by our Oil Engineer who works in conjunction with laboratory and field.

Thus conditions peculiar to a certain project or type of material can be brought to the attention of the laboratory for further analysis and for correction where possible and where needed.

Paint seal coats are specified as part of the contract on new projects and for all MC-3 mats this has called for RC-2. On all maintenance work which, of course, calls for resealing SC mats we have, in the light of past experience, set up a special RC-1-A seal coat material, which calls for a lighter diluent and a lower penetration base asphalt. This was specified with the purpose in view of obtaining a material which would dry more quickly and which would also penetrate the surface to a greater depth preventing setting up on top which had caused serious trouble from slipperiness. Favorable reports have been received for this material which was specified this season for the first time.

Working in conjunction with the field maintenance men the laboratory has developed a formula for center-strip paint. Considerable difficulty has been experienced with application and drying time but under our present specification both these conditions have been eliminated.

In our department both funds and personnel have been too limited to permit of extensive research and therefore, in the preparation of this paper, I have had to confine myself largely to what our practices have been in the past and what steps we have taken to accomplish better and, we hope, more permanent results. Fortunately, conditions at the present, seem to indicate more possibilities for future research work and needless to say we will avail ourselves of the opportunity.

Progress in Research

Report Prepared for the Montana National Bituminous Conference, 1937

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During the past year this department has devoted time to research on several subjects connected with bituminous construction.

A final report has been prepared on a study of the penetration test for asphalt. Results obtained indicate that some of the steps described in the Standard A.S.T.M. method can be conducted with considerable variation from prescribed conditions with greater convenience and without affecting the results of the determination. It was also found that other steps as described were not restricted sufficiently to yield unvarying results when conducted over the range of conditions permitted by the standard method.

Some work has been done on a similar study of the Standard A.S.T.M. Float Test. The use of the Asphalt Tip in the Saybolt viscosimeter is being studied as an alternate method of determining consistency of products for which the float test is now used.

A great deal of study has been concentrated on the subject of the adhesion between asphaltic films and aggregates. Our laboratory work has served to point out a variety of conditions that affect adhesion. The results in the laboratory have been so clearly defined in some instances as to indicate strongly that observed variations in adhesion must obtain in similar degree in the field as a result of natural conditions. As a matter of fact, excellent correlation between laboratory tests and field behavior have been noted in some instances.

In planning a program of study of adhesion phenomena, it was felt that the first step should be the selection of an existing test method or the development of a new method which should be used consistently throughout the investigation. Having established a test method, the next step would be to study examples of good and poor results in construction in which the credit or blame could be ascribed, in some degree at least, to the characteristics of the aggregates.

This department has depended in the past largely on the swell test to determine the adhesion characteristics of aggregates. Recently, however, there have been described in the literature a variety of tests involving the stripping of bituminous films by agitation of the coated aggregate in water.

A number of stripping tests were investigated in our laboratory. Briefly, we found that aggregates showing relatively good results in the swell test could be made to lose part or all of their coating by vigorous agitation in water. One of the troubles with such test, however, was in expressing the results in more than general terms such as ''little stripping'' or ''much stripping.'' Another difficulty arose in distinguishing between results obtained on what we felt were good and poor aggregates.

It was finally discovered that a quantitative separation could be made between stripped and unstripped particles that were finer than 100 mesh. The method of making the separation was simply to wash the bituminous mixture, after agitation in water, through a 100 mesh sieve. Stripped particles pass the sieve while those that have held their coating are retained.

In order to simplify matters at the start it was decided to confine tests to coarse aggregate which had been crushed, screened and recombined to a standard grading between 0 and ¼ inch. The grading adopted contains 18 per cent passing 100 mesh. As a further simplification, it was decided to use SC-2 oil only in the tests. The oil and aggregate are mixed as for a swell test. The mixture is then available for swell tests or for the stripping test which we have termed the wash test. In the latter test the mixture is agitated in the presence of water in an Erlenmeyer flask attached to a Ro-tap sieving machine. The stripped material which has been washed through a 100 mesh sieve is recovered and weighed. The results are expressed as a percentage of the weight of 100 mesh material present in the original sample.

Results are thus obtained which may range in value from zero to 100 per cent, or possibly higher. We have obtained results well distributed through the range from 5 per cent to about 90 per cent.

At first the results obtained in the wash test were decidedly erratic. We have been able, however, to standardize the procedure to the point where satisfactory checks are obtained.

The search for causes of variations in results was very enlightening and served to focus attention on a number of phenomena which in all probability would otherwise have escaped notice.

During our study of the wash test, swell tests were made on many of the prepared mixtures. It was found that the two tests could not be correlated in many instances. At the present time, we have insufficient data to warrant an opinion as to which gives the more significant answer. It is not the purpose of this report to discredit the swell test in any way. It is considered an ingenious test of great value. We believe, however, that it is used frequently without full appreciation of its possibilities of interpretation.

One of the most important findings of our studies was that the adhesion of all the aggregates examined improved with age after mixing with oil. This improvement was found to take place rapidly during the first few days of curing at 70° F. The rate of change decreased gradually and the adhesion finally reached a constant value after periods ranging from a few days to a month depending on the aggregate in question. If the mixture was cured at 140° F., it was found that the change in adhesion per hour was very close to that obtained per day at 70° F.

An example of this result which occurred naturally was noted in the case of aggregate from a certain gravel pit. Freshly made laboratory mixtures showed high percentages of wash which decreased with curing. A stockpile of this aggregate mixed with SC-2 oil several months previously was sampled and was found to yield a very low percentage of wash.

In another instance a road mixed surface constructed with aggregates of decidedly inferior adhesion was found to have been ravelled and abraded by traffic to a very serious extent. This surface is in a dry section of the state, but showers occurring for a few days prior to day of inspection had left pools of water standing on the roadway. The oil mixture beneath and adjoining the water showed no signs of softening or stripping. Since the inspection was made five years after construction, it seems evident that the adhesion of the oil to the aggregate which was so poor at first as to permit serious damage to the road has finally improved to an extent to which further rapid deterioration seems unlikely. At any rate this effect is indicated by the observations noted above and by laboratory tests.

What happens to age-old rocks and gravels that causes them to improve in adhesion so rapidly after they are crushed and coated with bitumen? We believe that we have found a partial answer to this question in our laboratory tests. These tests indicate that the ability of an aggregate to retain a film of bitumen in preference to water is never a constant quantity, but varies in accordance with the atmospheric conditions with which equilibrium is established.

Rock or gravel in place in the quarry or pit usually is subjected to rather damp conditions. When oil mixtures are made from fresh samples swell and wash tests are found to be relatively high. If the aggregates are stored for a period of time in the relatively dry atmosphere of the laboratory and then are mixed with oil the adhesion expressed by swell or wash tests improves. The improvement in adhesion characteristics is not, however, necessarily permanent. We have found that if the air-dried aggregates are then exposed to the humid air of the moist room for a period of time, and are then mixed with oil, wash tests return to the higher values obtained with the fresh samples.

Here is one place where wash tests do not agree with swell tests. Aggregates after exposure in the moist closet show some increase in swell, but we have not found the result to return to the higher value obtained on the fresh sample.

Based on the observations described above, we have evolved a theory which may or may not be in accordance with the facts. Adhesion of bitumen to the aggregate appears to be impaired by absorbed or adsorbed water. After the aggregate is coated with a film of bitumen the contained water may escape slowly if exposed to drying conditions. After the aggregate has lost its contained water the bitumen adheres more strongly and is not then so readily displaced by water from the outside. This theory takes no account of changes in the characteristics of the bitumen that may occur on exposure and this may be a factor.

The higher the temperature to which the aggregate or mixture is heated, the more rapidly does the adhesion improve. Aggregates that may not be suitable for road mixes may thus be found satisfactory for plant mixes if they are heated in the drier.

We have compared different lots of SC-2 oil in the wash test. While the results were not identical the differences appeared to be relatively insignificant when compared to those noted between different aggregates or the same aggregate under different curing conditions. It should be noted that the oils used in these tests were all from California fields.

Two aggregates showing the same swell and wash tests initially may improve at different rates during curing. It seems advisable, then, to determine the rate of change for purposes of evaluating the aggregate. Our tentative procedure is to determine the wash value of the mixture when freshly prepared and also after it has been cured at 140° F. for 4 hours.

Our laboratory investigations had led us to question whether correct reasons have been ascribed to occasional failures of nonskid seal coat rock to stick to the underlying oil. Possibly the characteristics of the aggregates have been responsible to an extent greater than has been realized. Nonskid treated surfaces are opened to traffic very shortly after the chips have been applied. With this procedure, the aggregate is in its poorest condition with respect to adhesion and it is subjected to large forces tending to remove it from the roadway.

Probably it should possess adhesion to a greater degree than is essential for other types of bituminous construction.

It seems reasonable to conclude that aggregates for road mix should have better adhesion characteristics if construction is to be done in the fall with wet weather impending than are necessary for early season construction when warm dry weather can be expected to improve adhesion.

What may happen to the adhesion of aggregates placed in stockpiles and which are not used for considerable periods after they are produced and tested is an interesting subject for investigation.

Although we have made but little study of adhesion towards different grades of oil preliminary experiments indicate that cutback materials should prove better than slow-curing oils. Acting on this belief, we altered the plans on one road mix project where the aggregates were of doubtful quality to call for MC-2 in place of SC-2 as originally planned.

It seems to be considered generally that siliceous aggregates as a class exhibit lower adhesion than do the more basic rocks. No doubt this is true as a rule, but we have had good success in certain cases with rocks such as granite, quartz and quartzite. On the other hand a basalt, which was highly altered, was found to be very poor both by laboratory test and by service record on the road.

In conclusion it may be said that our recent laboratory investigations have been particularly illuminating with respect to the phenomena of adhesion. They have brought a realization that tests previously performed without due regard to the condition of the sample at the time of test may have been misleading. The results of tests should, we believe, be interpreted in the light of the type of construction intended, the grade of oil to be used, and the climatic conditions of the locality of use with particular reference to the season of the year in which construction is to be undertaken.

Bituminous Research in Kansas

By

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The fall of 1930 marked the beginning of bituminous mat construction in Kansas. The construction of the first mats was assisted by information and personnel from other states, notably New Mexico, where this type of construction had been used for some period of time before the entrance of Kansas into this field.

The first project was most encouraging in its performance, giving a smooth, dustless surface at a relatively low cost, with a promise of a solution to the problem of low cost road surface construction. The success of the first project led to the construction of many miles of similar type roads. Variations in the original specifications to produce lower cost surfaces, gave surfaces which, in some cases were unsatisfactory, although their life and the experience gained from their construction justified their cost. With the increased use of this type of construction, it soon became evident that all such surfaces did not give satisfactory service, and it was also evident that the reasons for the unsatisfactory service were not always clearly understood.

The first comprehensive research to define more clearly the behavior of bituminous surfaces was begun in 1931. The research consisted of two parts, the first an analysis of new materials to determine their behavior, and the second part an analysis of existing mats to determine more closely the reasons for success or failure.

The research on new materials used swell, stability and impact tests to determine the mixed aggregate characteristics. A series of five investigations were used. These were, first, to provide data for the comparison of mixtures of aggregates and road oils available in Kansas, second, to study the effect of oil content on the behavior of mixtures, third, to study the effect of the material passing the 200 mesh sieve, fourth, to study the characteristics of field mixtures, and fifth, to study the characteristics of the New Mexico formula by which the oil content of the mixtures was determined.

The results from this series were evaluated as follows: The oils from all the refineries investigated have equal value as binders; the value of mineral fines could be rated as follows: The first being found the most satisfactory: Limestone or rock dust, silica, river silt, sand and chat sludge. The most satisfactory results were obtained with from 5% to 7% oil content. It was found that from 5% to 15% of the total aggregate must pass the 200 mesh sieve to produce the most satisfactory results. Top soil from shaley material, when pulverized, was found to be satisfactory for use as fines. The constants in the New Mexico formula were verified by laboratory tests.

The second portion of the investigation was the sampling and extraction of the asphalt from a number of mats in service for one or more years. From this research, it was discovered that those asphalts having a high percentage soluble in Carbon Tetrachloride were producing surfaces of better quality than those materials having low solubilities. It was also noted that those materials which had good ductilities at low penetrations when reduced to low penetrations by method A.S.T.M. D 243-28T were producing mats of better quality. These results were incorporated in new specifications by specifying a solubility of 99.0 in CCl_4 for road oils and a solubility of 99.5⅝ for all distillation residues of cutback materials. The low penetration ductility specification was included as follows: All material having a positive Oliensis spot is required to have penetration-ductilities of the following order: SC oils, penetration 15 to 25, ductility not less than 50 cm. (5 cm./min. 77° F. penetration reduced by A.S.T.M. D 243-28T).

MC cutbacks, penetration 25 to 35, ductility of not less than 50 cm. RC cutbacks, penetration 40 to 50, ductility of not less than 50cm. The low penetration ductility requirement is an alternative for negative Oliensis material. Both positive and negative spot test asphalts have been used since the date of this research and are being used at the present time.

At the date of the first comprehensive research survey, the asphaltic oils used were largely of the SC or road oil classification. Since that date, the SC or slow curing type oils have been largely displaced by material of the MC cutback classification.

At this time, in our opinion, material of the MC cutback classification apparently has a number of advantages over the SC or slow curing type of asphaltic material. The first of these is the development of stability, in the asphaltic material within a short curing period by loss of controlled volatile material. Through the development of asphalt stability, the critical point of maximum asphalt content in the aggregates is raised above that of aggregates containing slow curing oils, and the danger of too high an asphalt content with consequent corrugating and rolling is lessened, though not eliminated. The use of harder asphaltic material as in cutbacks, may minimize the danger of stripping of asphaltic films by water action. It also seems apparent that greater stability values of the aggregates can be obtained with more loosely graded aggregates, the gradation limits can therefore be extended in some cases, enabling the use of materials capable of being produced at a lower cost. Whereas the fines content of the mixed aggregate in SC mixtures must be closely controlled, the MC cutback material may be utilized to broaden the lower limits of fines content, in some cases, the fines have been reduced to a very low limit or eliminated without apparent loss of stability.

At this time the apparent disadvantages of MC cutback material lies in higher cost of the asphaltic material compared with the SC oils and in the danger of under-asphalting the aggregates. It has been found that some engineers, experienced in the use of SC or equivalent oils where constant vigilance had to be exerted to prevent over-asphalting of the mix, encounter difficulty in securing a sufficient amount of MC asphalt in the mix, The looks, feel and ''life'' of the MC mixed material immediately after mixing and before initial curing has been completed, is deceptive. A mix apparently having sufficient asphaltic material under these conditions, will often, after the mat has been laid and the curing period completed, which may require from several days to several weeks, begin to ravel, crack, or lose compaction due to insufficient asphalt binder. Remixing or sealing is usually necessary to correct the difficulty. In our opinion the greatest advantage of MC material apparently consists in the raising of the higher critical limit of asphalt content in dense type mixes, and also for use in loosely or coarsely graded aggregates. If a mix is under-asphalted, the MC material apparently has little or no advantage over the SC type asphaltic oils. The comparative durabilities of MC cutback material will be taken up in the discussion of 1936 research.

Although the extensive use of MC material began in 1933 in Kansas no comprehensive research as to the durability of this type of material was undertaken until June, 1936. At that time an investigation of mats constructed during the 1935 season was begun. Eight projects over the state were selected to give a representation of all the asphaltic material being used. These mats were of the dense type, having closely graded aggregates with an appreciable amount of material passing the 200 mesh sieve. These samples were extracted by the Bussow method (AAPT, Pro. 1936) and the recovered asphalt subjected to laboratory tests.

Twelve samples were taken from the eight projects. The penetration of the distillation residues secured from the original asphalt were from 109 to 151. All of the residues had ductilities of 100+ in the original material. The material sampled had been in service for periods from 9 to 11 months, with the exception of one, which had a service of 4 months. It was found that all the extracted material, with the exception of the 4-month sample, had dropped in penetration to, in two cases, 45 penetration, and in one case to 13. The remainder varied between these two points. The ductilities had dropped, in the 13 penetration sample, to 6 cm. Six samples were below 20 cm. ductility. Two samples gave 45 penetration, both of which were originally positive Oliensis material. Two negative samples were included in the 9 to 11 month service class, these samples gave penetrations of 40 and 37 respectively, with ductilities of 27 and 80 cm.

These figures indicate that hardening below the distillation residue penetration had progressed at an excessive rate, much faster than had been expected. The values of the characteristics of the extracted materials indicated that some asphalts had become hard and brittle, and that these mats were no longer in a flexible state, but would be very critical to subgrade conditions, leading to cracking, raveling, and other disintegration. One mat had cracked badly due to this cause.

It is interesting to note that a sample of the original mat constructed in 1930 was recently extracted, and this mat yielded fluid asphalt, with a Saybolt Furol viscosity of 2250 seconds, 140° F. This original mat is still in excellent condition, portions of which have been sealed only within the past year. Any superiority of MC asphalts over the SC type in regards to serviceability is therefore seriously questioned.

The results of the 1936 investigation has led to an extensive program of research for 1937. Through several methods of attack, the causes of the rapid hardening of the asphaltic material are being investigated. Samples of asphaltic material have been obtained from six refineries which have been supplying material to Kansas for road construction. The samples include SC, MC, and RC oils in regular production at the refineries. This material has been subjected to a number of the physical and chemical tests with which to correlate the results of the extraction tests.

All of the 1935 construction projects sampled in 1936 have been resampled in May, 1937, at adjacent points to the 1936 sampling and a number of 1936 projects have been included in the investigation. The results of these extractions are not available at the time of writing.

As an assistance in determining the actual stability of mat surfaces a circular testing track similar to that of the USBPR has been constructed at the laboratory, Kansas State College, Manhattan, Kansas. The track is completed and available at the time of writing, but has not been used due to the press of other research work. With this research tool, it is hoped that it will be possible to establish the minimum factors of important physical properties of the asphaltic materials necessary to preserve integrity of the mat surfaces under definite maximum instability conditions of the subgrade. The effect of variations in the gradations of aggregates will also be studied, and it is hoped that important information regarding subgrades will be secured.

Research is being conducted on the changes occurring in asphaltic material due to weathering and the effect of heat, various gases and light radiations. The tests being conducted are microscopic. Thin translucent films of an approximate thickness of 0.001 inch are placed on microscopic slides and exposed to the action of heat in air and in various other gases, artificial light of various spectral distributions, and sunlight. At the date of writing, some very interesting reactions have been obtained on these films. It has been found that some materials give severe reactions at both high (325° F.) and low (140° F.) temperatures. Some material which does not react with heat alone, can be induced to present reactions when subjected to certain bands of ultra violet radiations. Films subjected to actual weathering also present reactions similar to those obtained with artificial means. This phase of research has not, at the time of writing, reached the point where definite conclusions can be made regarding the value of the reactions as an indication of the actual serviceability of the asphaltic material, but it is believed that this will be more fully understood when the results of the other phases of research being performed are correlated. It is hoped that the film study will lead to the development of a quality test.

The results of research on bituminous mats at the date of writing have indicated two major sources of difficulty. It is believed that present specifications controlling aggregate gradation for dense type mats are adequate from a stability viewpoint, when incorporated with a correct quantity of asphaltic material, and this factor is therefore not considered as a major research problem at the present time.

The first of the two major factors causing unsatisfactory service may in our opinion be defined as apparent failure of the asphaltic material. By failure of the asphaltic material, is meant, in a broad sense, that changes have occurred in the material which have altered the considerations upon which the fundamental design of the structure was based. By this definition, failure may consist in the asphaltic material becoming hard, and with this hardness, brittleness, or perhaps the inability of surfaces, once parted, to rejoin and heal. Likewise, radical changes may occur in the ductility characteristics, which may decrease the bonding power or ability of the asphaltic material to hold the aggregate particles together. One of the basic premises of a bituminous surface is that the surface shall possess, in some degree, flexibility and the ability to adjust itself to minor changes in the supporting base without destruction of its structure. The cracking or raveling of a bituminous surface after a period of service, when subjected to certain deficiencies of the supporting base, should, it is believed, be considered asphaltic failure if the characteristics of the asphalt have changed, and the surface could successfully withstand similar conditions when first constructed.

The results of the current research have indicated that asphaltic failures under the definition given above may be caused mainly by two reactions. The first and simplest reaction is one of loss of volatile matter. When asphaltic material is exposed as a thin film, or exists in a mixture of aggregates as a thin film in which many pore channels are present, simple volatization may take place at a rapid rate. Research has indicated that the residue of distillation to 680° F. does not represent to any large degree the end point of volatile matter, but that this material under the conditions given above, may continue to lose volatile matter until, in some cases, an equilibrium point is reached at points far below that indicated in the original distillation residue.

In our opinion the second cause of apparent failure may be induced, as is evident in the laboratory research, by factors of heat, light and ultra-violet radiations and air. The exact nature of these reactions is as yet, in doubt. An actual oxidation is apparently present and with this may occur also polymerization of unstable material.

With what in our opinion is failure of the asphaltic material defined as one major cause of unsatisfactory service of bituminous surfaces, the second cause may be defined as failure of the supporting base.

Failure of the supporting base may occur from a number of conditions. One condition, not frequently found in Kansas, is that of a loose soil, difficult to compact and having small stability at any degree of moisture content. For this condition, some form of stabilization is evidently necessary. The second condition exists when material, which at an optimum moisture content possesses adequate stability for the loads to be carried, loses the necessary stability when the moisture content becomes greater or less than the optimum. Soils of this type are responsible for much difficulty encountered with mat failures when the bituminous surface itself is in a flexible, stable condition. Edge failures constitute a large maintenance item. Investigation of these failures present, invariably, the evidence that high moisture contents exist in these areas, and that the most prominent source of this moisture is in seepage through inadequately protected shoulder. An exchange of ideas from other states who have encountered or overcome this difficulty would be most valuable.

The economy of bituminous construction is of great importance. The stabilization of all subgrades for bituminous mats would constitute a large increase in cost of such construction, and from experience with bituminous surfaces in the past, it is believed that if existing subgrades can be sufficiently protected, stabilization need be necessary only in those areas where percolation, or seepage from underground sources, need be considered. It is believed that the use of improved asphaltic material, or the improved use of present material will tend to widen the critical limits of subgrade stability to the point where such limits can be practically maintained without undue cost.

The classification of bituminous surface failures as outlined above, are the premises upon which research toward solutions to the problems is being conducted. We have, for the moment, disregarded stability as an important factor, believing that our most pressing problem is one of durability and decreasing maintenance costs to within as low limits as possible, correcting the great discrepancy in maintenance costs which now exists between the existing bituminous surfaces.

In the definition of asphaltic failure several methods of attack are possible. The first of these is through the asphalt itself. For a successful long life of a bituminous surface, the asphalt must remain in a desirable state for that period. The hardening of asphalt may be controlled partially by elimination of asphalts which oxidize or polymerize easily. Hardening may also be controlled by rate of loss tests.

It is believed that an equally important method of attack on asphalt durability lies within the mat design itself, controlled by the factors of gradation of the aggregates and the amount of asphalt intimately mixed with these aggregates.

There has been some criticism in the past of the consumer of asphaltic materials, directed toward the producer, in the belief that the producer has not produced satisfactory asphaltic material. There have likewise been criticisms of the consumer by the producer for classifying as asphalt failures, failures which may be ascribed to other sources. An examination of research data accumulated during the past year has led to the conclusion that both criticisms are just.

It is believed that bituminous construction should be based on the premise that a dual function exists in the surface, first, that of the asphaltic material protection and integrating the other components of the surface, and second, the function of non-asphaltic components toward protecting and preserving the asphaltic material. The latter function, it is believed, has been much neglected and obtained only in a few surfaces.

From the viewpoint of subgrade conditions, there are many methods of attack on the problem, the deciding factor of which will probably be economic, depending on existing conditions, and availability of materials. Research is being conducted, experimental correction of subgrade faults are in progress, and the developments and experiences of other states are being watched with interest.

Progress in Research Plans, the Correlation of Research, Developments in the Fundamentals and Practical Design and Construction of Bituminous Surfaces

By

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In the fall of 1929 the first bituminous road mix project was completed by the North Dakota State Highway Department. This projert was built on a grade which at that time was considered above the average. The base course under the oil mat was approximately two to three inches of compacted gravel, feathered out toward the edge.

Since that time the Highway Department has been building both road mix and plant mix projects, with the tendency being more and more toward the plant mix type. We are satisfied that it is possible to obtain better control of the mixture when a plant mix is used, and our costs of the two are approximately the same. Plant mix, permits us to use road oils of higher viscosity and also permits the work to proceed earlier in the spring and later in the fall.

We have had some very satisfactory projects and also some that have given us a great deal of trouble. Most of this trouble has been traced directly to the base, which in some cases was not adequate to carry the traffic loads over the soft spots in the subgrade, and some of the subgrades would not give sufficient support to the gravel bases. Probably our worst condition has been shoulder breaks in the oil mat, which is undoubtedly caused by insufficient gravel base.

These various difficulties have led us to believe that it would be possible to correct such failures by changing our practice in construction of base and subgrades. Therefore, early in the spring of 1936 we commenced collecting information on stabilized gravel base material. After receiving this data some research work was undertaken in order to determine the procedure to follow which would permit us to use our local materials to the best advantage. We finally developed and wrote a specification which was purposely left fairly wide open in order to try and iron out some of the difficulties which might arise in the field under construction.

A few projects were started about the middle of the season and were completed with fairly good results.

During the construction of these first projects we tried laying one-half of the gravel and soil binder mixture and rolling it with loaded trucks which had dual tires. However, we found that this was not very satisfactory as it had the tendency to produce waviness in our gravel base. As a result of this experiment we required our contractors to equip themselves with multiple wheel pneumatic tired rollers of a pull type, which worked out very satisfactorily and gave us very good compaction. We have been able to obtain dry densities ranging from 125 to 150 pounds per cubic foot with an average of about 135 to 140 pounds per cubic foot.

Another difficulty we encountered in our earlier construction was the producing of a smooth surface on the second course of base material. When we used the pneumatic type rollers we found that it left our surfaces with a series of tire marks, which had a tendency to pool the bituminous material that was used for tack coat. In order to eliminate this rutting or tire tracks on the surface, we found it necessary to require our contractors to equip themselves with smooth steel rollers. This left our surface in a very receptive condition for the application of tack coat. We also found that by using a light treatment of water on the gravel base, before the application of the tack coat, better penetration was obtained; this was especially noticable in drouth periods.

Still another difficulty to be overcome was that when rolling with pneumatic type rollers we had to be very careful not to start the roller when the base material was too moist. If the base material was too moist, pneumatic tires on the roller had a tendency to suck the soil binder to the surface in much the same manner as the troweling of concrete. However, after our engineers had gained a little experience in judging the time at which to start the roller, this condition was soon eliminated.

We have used both plant mix and road mix stabilized material for bases and it appears that the plant mix is giving us a more uniform mixture. One other advantage in plant mix is that after a rain the contractor is enabled to proceed with the work a little earlier than when using road mix, particularly if the soil binder is not properly mixed with the gravel when it rains. However, at this time we are taking several samples from different projects in order to determine just what variation there is in the same project when plant mixed or road mixed. After we test these samples and obtain the results we believe we will be in a fairly good position to state which is the more desirable from the standpoint of uniformity of mixture of soil binder and gravel.

Our standard practice at the present time is to use a six-inch loose measurement quantity of gravel and add the necessary soil binder to it on subgrades that are of the A-4 to A-8 type. On those that are of the A-1 to A-3 type we are going to use four and one-half inches of loose measurement quantity of gravel with the necessary soil binder added to it. In the first case this will give us a compacted thickness of approximately five and one-half inches, and in the second case a compacted thickness of a little better than four inches. These gravel bases are to be built three feet wider than the bituminous mat, which we believe will considerably reduce shoulder breaks. At this time we have two bituminous mats which are one year old, constructed on the above mentioned type of base, both of which have passed through a very severe winter and wet spring and are in very good condition.

By the end of this season we will probably have several more projects on which a bituminous mat is placed upon stabilized gravel bases. At present we are constructing these bituminous mats two and one-half inches thick, but on future work we intend to use a mat an inch and a half in thickness as we believe this will be all that is necessary and will be a great deal more economical. We are also planning to apply a tack coat of approximately one-half gallon per square yard, of either Tars, MC-2, or SC-2 to some of our stabilized bases, and in some cases we intend to apply a seal coat of RC-2 after we have placed the tack coat, with approximately twelve pounds of sand per square yard. We believe these light treatments will prove satisfactory in certain sections of the state where the traffic is very light and will ultimately reduce our maintenance costs.

We also have in mind trying a project or so which has stabilized base with a very light mulch treatment of pit run gravel with a maximum size of approximately one-half inch and tars or MC binders.

It is our contention that these three types of bituminous treatment, when built on stabilized gravel bases, should be adequate for most of the traffic in this state.

Bituminous Research in Nebraska

By

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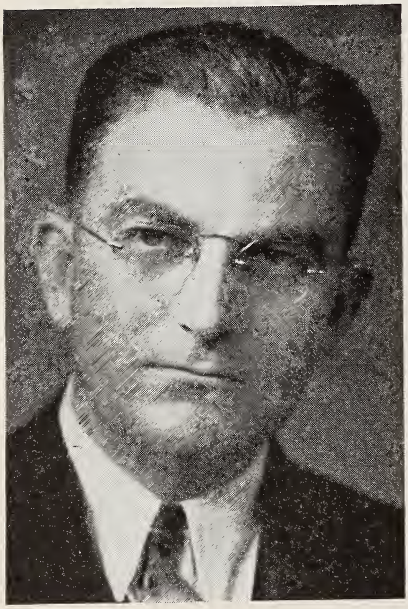
INTRODUCTION



Nebraska does not have a separate research organization and all laboratory research is done by regular employees working in the materials testing laboratory.

A definite appropriation for research is not made and consequently an organized system of research is not followed. However, a considerable amount of work has been done in connection with the design of bituminous mixtures and the development of specifications. This has necessitated several specific researches on bituminous mixtures, asphaltic oils and aggrgates. The work done in the laboratory will be summarized later in this report.

The research work may be divided into three classes: (1) Research work done on materials and mixtures in the laboratory for general information. (2) Special and regular construction projects which are so set up as to permit specific comparisons between different methods of construction or between different materials. (3) Research work done both in the laboratory and on the construction project to correlate field data to laboratory data.

SUMMARY OF REPORTS ON LABORATORY RESEARCH

Summary Ident. No.	Date Reported	Subject
(1)	April, 1932	Preliminary Report of Research in Bituminous Aggregate Mixtures.
(2)	January, 1933	Preliminary Report of Analyses of Road Oils Used in 1932.
(3)	January, 1933	Report of Cutback Asphalt Research.
(4)	May, 1933	Supplemental Report of Research in Bituminous Aggregate Mixtures.
(5)	April, 1935	Stabilizing Effect of Filler and Asphalt in Bituminous Sand Mixtures.
(6)	December, 1936	The Use and Selection of Mineral Fillers for Low Cost Roads.

LABORATORY RESEARCH IN PROGRESS

Summary Ident. No.	Subject	Status of Report
(7)	Bituminous Soil Stabilization.	Incomplete
(8)	Aeration of Bituminous Mixtures.	Incomplete
(9)	Continuation of Filler Research.	Incomplete

SUMMARY OF FIELD RESEARCH PROJECTS IN PROGRESS

Summary Ident. No.	Date Constructed	Project or Patrol No.	Purpose or Subject	Where Reported
(10)	1930	F.A.P.313-A	Low Cost Bituminous Road Investigation. Experimental Bituminous Sand Surfacing.	Project No. 233, 1932 A.A. S.H.O. Committee Report Highway Research Activities.
(11)	1931	681 B&C	Bituminous Sand Surfacing to compare four kinds of Road Oil	Departmental Construction Report Periodic condition Surveys. Not published.
(12)	1931	Patrol 112	Experimental Colprovia Bituminous Mat.	Departmental Construction Report Periodic Condition Surveys. Not published.
(13)			Havelock Experimental Road.	Departmental Materials and Construction Report Periodic Condition Surveys. Not published.
	August, 1933	Section I Patrol 100	Experimental Bituminous Mat. Asphalt Emulsion-cold laid, hot plant mix.	
	August, 1933	Section II Patrol 100	Experimental Bituminous Mat. Road Oil-cold laid. hot plant mix.	
	Sept. 1933	Section III Patrol 100	Experimental Bituminous Mat. 94 Road Oil. Cold laid, hot plant mix.	
	Fall, 1932	Section IV Patrol 100	Experimental Bituminous Mat. Reconstruction of Exp. Bit. Mat constructed in 1928. Blade Mix.	
	Sept. 1934	Section V Patrol 100	Experimental Bituminous Mat. Asphalt Emulsion-cold laid, cold plant mix.	

Summary Ident. No.	Date Constructed	Project or Patrol No.	Purpose or Subject	Where Reported
	Sept. 1934	Section VI Patrol 100	Experimental Surface Treatments. RC-1 and RC-2 Prime. RC-2 and Asphalt Emulsion Armor Coat.	
	Sept. 1935	Section VII Patrol 158	Experimental Tar Mat. Special and regular gradations. Blade Mix.	
(14)	1934	282	Experimental Bituminous Mat using lime rock with regular sand gravel.	Departmental Condition Surveys. Not published.
(15)	1935	133 B&F	Experimental Bituminous Mat. Comparing cracked and uncracked MC asphaltic oils.	Condition Surveys. Not published.
(16)	1935-1936	WPH 268 A and 268 A	Regular Bituminous Mat constructed on experimental stabilized soil base course.	Condition Surveys. Not published.
(17)	1936	157 D	Experimental Surface Treatments on regular stabilized soil base course.	Condition Surveys. Not published.

SYNOPSIS OF LABORATORY RESEARCH REPORTS

The synopsis will be given for each of the reports or projects previously mentioned, in the same order, and with the same numeral designation followed in the research summary.

(1) The "Preliminary Report of Research in Bituminous Aggregate Mixtures" indicated the following conclusions:

(a) In the coarser bituminous mixtures containing Platte River Sand Gravel (rounded, smooth surface particles) it is necessary to use 10 to 15 per cent of material passing the No. 200 sieve where Road Oil (similar to SC-2 or SC-3) is used as binder. In the finer mixtures 15 to 20 per cent of material passing the No. 200 sieve is necessary to produce a satisfactory stability.

(b) In order to assure stability in all cases it is necessary to have a well-graded mixture.

(c) A considerable difference was noted in the stabilizing action and the quantity of bitumen required in several fillers. This indicated the need of additional tests to show the effect of these differences more completely.

(d) The effect of a change in viscosity of the bitumen on the bituminous mixtures was also demonstrated.

This report has not been published but is on file at the Highway Testing Laboratory.

(2) The "Preliminary Report of Analyses of Road Oils Used in 1932," showed many differences in road oils which met the same specification. As new tests are developed these tests are made on samples of the oils kept for this purpose. Large composite samples of each type of oil supplied from each refinery, on construction projects, are now preserved each year and many different tests are made on these samples during the winter months.

This report is on file at the Highway Testing Laboratory.

(3) The "Report of Cutback Asphalt Research" shows the tests made at Casper, Wyoming and also at Lincoln, Nebr., on a series of asphalt and distillates made up into cutback. The effect on the test results as a consequence of testing at different altitudes, and the effect of different percentages of distillate and asphalt base are shown.

This report is on file at the Highway Testing Laboratory.

(4) The "Supplemental Report of Research in Bituminous Aggregate Mixtures," covers research work done from April, 1932, to May, 1933. A denser gradation and more stable bituminous mixture was developed from this research. The effect of filler on oil-filler mixtures is shown, and a test was developed for distinguishing fillers which require more oil than others.

This report is on file at the Highway Testing Laboratory.

(5) The report on the "Stabilizing Effect of Filler and Asphalt in Bituminous Sand Mixtures," shows the relationship of the consistency of the asphalt and the kind and percentage of material passing the No. 200 sieve, to the stability of bituminous sand mixtures.

The use of the "S" factor in designing bituminous sand mixtures and also in proportioning the asphaltic oil is demonstrated.

When fillers which contain only a small quantity of clay are used in laboratory mixtures, it is necessary to control the temperature and time of mixing very closely in order to reproduce results. Remixing and retesting of mixtures of this kind was found to be impossible due to the increase in stability caused by the further break-down of small filler aggregations.

This report is on file at the Highway Testing Laboratory.

(6) The report, "The Use and Selection of Mineral Fillers for Low Cost Roads," covers work done during the past five years on mineral fillers and gives a number of conclusions arrived at both in the laboratory and from correlation with field conditions.

This report is published in the 1937 Proceedings of the Association of Asphalt Paving Technologists and is also on file at the Highway Testing Laboratory.

Description of Laboratory Research in Progress

(7) Bituminous Soil Stabilization.

An investigation is now being made of different mixtures of soil and asphaltic materials to determine the effectiveness of various bituminous treatments. Several projects are being constructed in which this information was used as a guide in their design and construction.

(8) Aeration.

A study is being made of different methods which might be suitable for field use to determine the degree of aeration of bituminous mixtures containing cutback asphalt. A method of test which is proving successful is included in this paper. This test will remove all of the distillate, which distills over at 680° F. in the standard distillation test, from a sample of bituminous aggregate. A report of the work completed will be made during the fall or winter months.

(9) Continuation of Filler Research.

Each year a complete analysis is made of a composite sample of each filler used in bituminous mat construction. This analysis includes all of the tests made on soils, asphalt-water preferential tests, swell tests and other quality tests. An attempt is made to correlate this data with the behavior of the material in service.

Description of and Conclusions Reached from Field Research Projects

(10) Project 313 A.

1. In the construction of bituminous sand roads in Nebraska it is necessary to use from 10 to 20 per cent of material passing the No. 200 sieve when slow curing asphaltic oils are used.
2. It is necessary to thoroughly aerate the medium curing asphaltic oil in the bituminous sand road in order to avoid an unstable condition in the lower half of the surfacing. This unstable condition causes excessive cracking of the surface and allows moisture and blow sand to enter the cracks.
3. The maintenance of the bituminous surface has cost approximately $75 per mile per year over a period of 4 years.
4. The surface is in fairly good condition and will need very little repairs during 1937.

(11) Project 681 B&C.

Considerable difference was found in the road oils, from the four different refineries, which were used on this project.

The outstanding difference noted was the formation of a black oxidized crust on the bituminous sand where one oil was used. This oil showed evidence of more cracking than the other three oils when tested by the Oliensis Spot Test.

Samples of this crust extracted with 86° Baume Naphtha and then wth CS_2 showed that the oil contained about 38% of Asphaltenes compared to 18% in the original oil. The asphaltene content of the other oils increased from 18% in the original oil to 23% in the oil in the surface crust after two years' service. Several sections of the surfacing on this project, containing the highly cracked oil and which showed satisfactory stability and bitumen content, have required reconstruction because of raveling and disintegration of the oxidized surface crust.

Insertion of a negative Oliensis Spot Test requirement in the specifications has eliminated road oils which might have caused this type of failure, but also has eliminated road oils which have proven satisfactory.

(12) Colprovia Bituminous Mat.

This mat was constructed to study this type of construction and also to study the results obtained by using different types and quantities of filler.

Several short sections became slightly unstable due to the use of too much bitumen. The greater part of the mat remained in good condition and now is almost as hard as an asphaltic concrete pavement. The high stability of the mat has retarded subgrade and edge failures.

No advantage was found in the use of limestone dust in place of "Loess" filler in this mat.

During the second and third years after the construction of this mat a considerable number of blisters approximately ⅜ inch in height and diameter formed on the surface in scattered areas. The cause of these blisters has not been determined.

(13) Havelock Experimental Road.

The bituminous mat on this road was constructed in order to study various asphaltic materials in service and to determine the effect of different thicknesses of the mat.

The superiority of the higher viscosity and uncracked asphaltic materials was demonstrated on this road. In all of the first six sections constructed the necessity of having a stable subgrade or base was definitely shown. Subgrade or base failures has been the major cause of repairs on all the sections.

The two-inch thickness mats were easier to lay than the inch and the inch and one-half mats but the additional thickness has not been justified as far as reducing maintenance costs is concerned.

The experimental tar mat has not been in service for sufficient time to draw any accurate conclusions, however several interesting things have been noted.

One of the claims of the tar producer was that a smaller quantity of tar than asphaltic oil would be required. The percentage of tar recommended by the tar producer was used and it was necessary to apply a heavy seal coat immediately after construction. Approximately four-tenths gallon per square yard was applied as a seal, the major part of which penetrated to a depth of ¾ inch in the mat. This was covered with approximately twenty pounds of sand per square yard. The stability of the tar mixture before laying the mat was between 2000 and 3000 pounds in the 4-inch diameter Hubbard-Field type mold compared to a stability of 8000 to 10,000 for similar mixtures using MC-2 asphaltic oil.

The tar mat did not rut but showed tire marks and hoof prints both before and after sealing. It is in good condition and very smooth at the present time.

Most bituminous mats rut considerably where the stability is less than 6000 pounds.

(14) Project 282: Experimental Bituminous Mat Using Lime Rock Aggregate.

The construction on this project was the same in all respects as the regular bituminous mat construction except that Class ''D'' aggregate was used to replace 40% of the Class ''A'' or standard aggregate. The Class ''D'' aggregate is a soft, relatively unsound material in comparison to Class ''A'' aggregate and requires approximately twice as much oil as Class ''A'' aggregate due to its high absorption.

Approximately 25% more MC asphaltic oil was used in this mat than would have been used if all of the aggregate had been Class ''A.'' The cost of the mat was higher than the standard design mat. The mat is in good condition at present.

(15) Project 133 B&F—Experimental Bituminous Mat. Comparing Cracked and Uncracked MC Asphaltic Oil.

MC-3 Asphaltic Oil testing negative in the Oliensis Spot Test was used in the mat on about 11 miles of this project, and MC-3 asphaltic oil testing positive in the Oliensis Spot Test was used on 3 miles of the mat. It was reported by the refinery supplying the oil that the cracked MC-3 asphaltic oil was very highly cracked and the nature of the Spot indicated this.

No difference has been noted between the two sections containing these two asphaltic oils during a period of one year.

(16) Project 268 A—Experimental Stabilized Soil Base Course Construction.

Construction was started in the fall of 1935 and completed in the summer of 1936. Twenty-five sections of varying lengths were constructed making a total length of 12 miles. Each section was different from the other sections in either depth of base course, plasticity index of soil fines, gradation or type of aggregate. A two-inch bituminous mat was constructed on the compacted and primed stabilized soil base course.

This project is being studied in co-operatin with the U. S. Bureau of Public Roads. A representative of the Bureau was present during the initial construction and made periodic inspections during the remaining stages of construction. Several condition surveys have been made by the Bureau, and additional condition surveys will be made from time to time.

A field laboratory was maintained during all of the construction. Before the stabilized soil mixture window was spread for laying, samples were taken at 500-foot intervals and oftener when changing from one section to another. Samples were tested both in the field laboratory and in the Lincoln Laboratory.

After the stabilized base course mixture was laid, compacted and primed, several samples were taken from each section and tested in the field for compacted dry bulk density. Several duplicate samples from the base course in each section were taken and sent to the Bureau of Public Roads Laboratory and also to the Lincoln Laboratory. As some of these samples were taken after the base course was primed, a small quantity of the asphaltic oil prime coat was found in some samples making it necessary to extract this oil before the soil test could be made. The bituminous surface is in excellent condition at the present time.

(17) Project 157-D—Experimental Armor Coats on Stabilized Soil Base Course.

This project was constructed in August, 1936, and is divided into two sections which are each approximately 4.5 miles in length. The stabilized soil base course mixture is the same on both sections.

On one section MC-1 prime was used followed by an armor coat of about 0.25 gallon of RC-2 asphaltic oil per square yard covered with about twenty pounds of armor coat aggregate.

On the other section TC-2 prime was used and was followed by 0.2 to 0.25 gallon of TM-2 tar per square yard covered with about fifteen pounds of armor coat aggregate. The TM-2 tar was too light a grade to use on this type of work as it had a tendency to flow off the roadbed and did not hold as heavy a cover coat of aggregate as did the RC-2. The surface of the finished road is much darker where the tar was used than is the surface where the RC-2 was used. This is very noticeable at night.

A second armor coat of TH-1 Tar was placed on the tar treated section and a second armor coat of RC-2 was placed on the asphaltic oil section in June, 1937.

The maintenance of the armor coat during the first year consisted mainly in sealing shrinkage cracks caused by the subgrade. Tire chains and farm tractors caused a small amount of abrasion and rupture of the armor coat.

NEBRASKA METHOD OF TEST FOR THE QUANTITATIVE DETERMINATION OF DISTILLATE IN BITUMINOUS MIXTURES

(June, 1937)

1. Scope

This method is intended for the determination of the quantity of distillate or volatile material in bituminous mixtures. When the percentage of asphaltic oil in the bituminous mixture is known, the ratio of the percentage of distillate in a bituminous mixture after aeration to the percentage of distillate in the same mixture before aeration can be calculated from the results of tests made on these mixtures. It is necessary to perform one test on the aerated sample and a duplicate test on a similar sample which has not been aerated.

2. Apparatus

(a) General. The apparatus shall consist of a glass flask or metal still, heated by a suitable gas burner or other heating device, and provided with a reflux water condenser discharging into a trap for collecting the distillate. The trap serves to collect and measure the diluent, returning condensed water to the still.

(b) Trap. The trap shall be made of well-annealed glass constructed in accordance with Fig. 1 (A.S.T.M. D 322-35, 1936). It shall be graduated from 0 to 12.5 ml. in 0.1 ml. divisions. The error of any indicated capacity shall not be greater than 0.05 ml.

(c) Flask. The glass flask shall be of the short-neck, round-bottom type, with a nominal capacity of 1 liter.

(d) Metal Still. When a metal still is used in place of the flask it shall be a vertical cylindrical vessel, having a faced flange at the top to which the head can be tightly clamped. The head shall be of metal and be provided with a tabulation 1 to 1½ inches in inside diameter. The still shall be approximately 4 inches in inside diameter and approximately six inches in height.

(e) Condenser. The condenser shall be of the water-cooled, reflux, glass or brass tube type, having a condenser jacket not less than 400 mm. (15-¾ in.) in length with an inner tube 9.5 to 12.7 mm. (⅜ to ½ in.) in outside diameter. The end of the condenser to be inserted in the trap shall be ground off at an angle of 60 degrees.

(f) Heating Device. A gasoline stove flame or an electric hot plate equipped with a sand bath may be used provided that a rate of distillation of 85 to 95 drops per minute from the condenser tip can be maintained.

3. Procedure

The sample shall be mixed thoroughly and 500 grams weighed and transferred to the flask. Approximately 350 cc. of water and 3 grams of Na_2CO_3 (soda ash) shall be added to the flask. Place a stopper in the flask and shake vigorously for about five minutes. The trap is then filled with water and the apparatus assembled. The tip of the condenser tube shall be placed directly over the indentation in the trap.

Heat shall be applied to the flask so that refluxing will start within from 5 to 10 minutes after the heat is applied. Note the time the first drop falls from the condenser tip. Regulate the distillation by increasing or decreasing the heat so that from 85 to 95 drops of water and distillate fall from the condenser tip each minute, beginning this rate not later than twenty minutes after the first drop and maintaining it for a period of three hours.

Some asphaltic oils contain more volatile distillate than others and it will be necessary to maintain a slower rate of distillation during the first twenty minutes of the test in order to avoid escape of vapors from the top of the condenser.

Readings of the amount of distillate in the trap shall be taken at 10 minute intervals during the first hour of the test and at twenty minute intervals thereafter.

At the end of the three-hour period the heat shall be removed. After standing for at least 15 minutes, to allow the distillate to settle clear and to cool to approximately room temperature, the volume of distillate shall be read.

Computations

$$\text{cc. of Oil in Bituminous Mixture} = \frac{\text{Weight of Oil}}{\text{Sp. Gr. of Oil}}$$

$$\text{Per cent Distillate Recovered} = \frac{\text{cc. Distillate in the trap}}{\text{cc. of Oil in Bit. Mix.}} \times 100$$

$$\text{Per cent aeration} = \frac{\begin{matrix}\%\ \text{Distillate in unaerated sample} -\\ \%\ \text{Distillate in aerated sample}\end{matrix}}{\%\ \text{Distillate in unaerated sample}} \times 100$$

NOTES ON THE AERATION TEST

Nebraska Highway Testing Laboratory

For the past four years our bituminous surfacing has been designed in an attempt to produce a surfacing having a satisfactory stability with as low a filler content and as high an asphalt content as was possible. In order to accomplish this with our aggregates and fillers, it has been necessary to aerate the bituminous mixture to decrease the penetration of the asphalt in the mixture.

The stability of the proposed bituminous mixture for most projects is checked by a laboratory stability determination which is very similar to the Hubbard Field Method. From a considerable number of tests made several years ago it was found that in almost all cases the stability was satisfactory in a correctly designed mixture if approximately one-half of the volatile was removed by aeration. This has been proven out in the field in many instances where samples of the bituminous mixture were taken from rutted mats laid without aerations and samples taken from the same locations after the mat was taken up and aerated.

LABORATORY METHOD OF AERATION

The method formerly used in the laboratory to aerate bituminous mixtures was to place samples in flat pans in an oven at 140 F. for 24 hours. The stability of the samples was determined before and after aeration and the percentage of volatile lost determined. This is the most reliable method we know but is quite slow for routine use. In this method unaerated mixtures containing MC-2 and MC-3 asphaltic oils lose from 10 to 12 per cent of their initial weight or approximately 50 per cent of the volatile. The RC-2 and RC-3 oils lose from 14 to 16 per cent of their weight or approximately 60 to 70 per cent of their volatile.

FIELD TEST FOR AERATION

The field aeration test has been developed in order to indicate the degree of aeration of the bituminous mixture in the windrow at any time. The field aeration test has been correlated to the laboratory aeration test on different mixes in order to determine the increase in stability with increased aeration.

By running preliminary tests on the unaerated mixtures and then testing the windrow at the same location at various intervals of time the degree of aeration is ascertained. It is not necessary to determine the bitumen content of the sample in order to determine the relative aeration.

NECESSITY FOR AERATION OF BITUMINOUS MIXTURES

In mixtures in which the aggregate consists of irregular shaped particles and has a high stability, the consistency of the asphaltic binder has a minimum effect on the stability of the mixture. In this case the aeration of the mixture before laying as a surface is of little importance. Aeration is not necessary from the stability standpoint in any bituminuos mixture which is deficient in bitumen.

In bituminous mixtures containing smooth rounded particles similar to Platte River sand gravel and Nebraska blow sands, the aggregate has a comparatively low stability. In this type of a bituminous mixture the consistency of the asphaltic material is of considerable importance if the bitumen content is the optimum or above. It is necessary to aerate these mixtures sufficiently to prevent rutting of the surfacing immediately after laying.

RESULTS OF OVER AERATION

Difficulty is experienced in the cold-laying of any bituminous mixture containing an asphaltic material of a penetration grade. This difficulty is increased as the consistency of the asphaltic material is decreased and also as the temperature of the mixture is decreased.

When a normal dense graded bituminous mixture containing cutback asphalt is aerated the difficulty of laying is increased. If the aeration is continued too far, that is to a point where chunks form in the windrow, it is almost impossible to lay a uniform thickness and produce a smooth surface. Material cut off the surface by blades in the final smoothing operations does not bond readily to the surface and a scabby or scaly appearing surface may result.

Aerating a mixture to a degree in which the asphalt stiffens and develops more cohesion to itself than adhesion to the aggregate is serious in cold weather. Poor compaction of the mixture is secured and the surface will ravel considerably during cold weather. If the bitumen content is correct this raveling ceases in warm weather and compaction will be secured under traffic.

Over aeration of properly designed bituminous mixtures during any time of the year results in a higher stability than may be necessary or than has been contemplated in the design. The high stability mixture is very apt to crack considerably due to temperature changes and to shrinkage of the base or subgrade. The high stability mixture does not heal as readily as lower stability mixtures.

SECTION II

Developments in Fundamentals of Bituminous Construction

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Introduction to Review by the Committee on Development of Fundamentals of Bituminous Construction

By

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As you know, in preparation for the Third Annual Montana Bituminous Conference, each highway department was invited to submit papers on subjects selected by the writers themselves, these papers to be grouped under the four major divisions of Research, Fundamentals, Construction and Maintenance. The response in the Fundamentals group was so generous and so varied in subject matter that a useful and comprehensive assembly of opinion and experience was obtained. Believing it to be their primary duty to consolidate and summarize this information, your committee has limited its formal discourse to the material furnished by these papers and has endeavored particularly to point out matters about which there are evident differences of opinion. In the oral discussion period to follow, however, you will be subject to no such limitation.

The subject of Fundamentals is not bounded by any sharp lines of definition, but rather is the filler in the sandwich between Research and Construction. We trust that those responsible for the review and discussions of those divisions will forgive our inadvertent trespasses on their territories as we shall forgive their trespasses on ours.

Originality, determination to improve results by a constant search for better methods, and eagerness to accept and apply proven improvements are gratifyingly apparent in every paper. There is an evident realization that new ideas must be based on sound fundamental principles and that the nature of our profession demands continued successes, as neither it nor the public condone failures.

Our review has indicated that the general subject of Fundamentals of Bituminous Construction may logically be presented in four subdivisions. These are:

Design of Subgrades and of Base Courses
Selection of Aggregates
Selection of Bituminous Materials
Design of Bituminous Mats

Design of Subgrades and of Base Courses

In the discussions of subgrades, thorough compaction of the foundation materials at their optimum moisture contents and adequate drainage of the roadbed continue to occupy the places of first importance. The soil profile plan for designing the subgrade for the most advantageous distribution of natural material is increasing in use. The simple physical soil tests originated by the Bureau of Public Roads are being widely utilized for examining the utility of these materials and for predicting their behavior when in place in the subgrade and foundation courses. A complete soil analysis involves several tests, each being of use in classifying and evaluating the material, but those most commonly employed are the liquid limit, plasticity index and shrinkage determinations. The soil tests are sometimes augmented by special load carrying capacity tests of subgrade and surfacing materials when dry and when at their liquid limits. Unfortunately, consideration of the immediate cost has in some cases caused failure to provide adequate equipment and personnel for carrying out complete investigational work and in others has delayed the application of the findings of the soils and laboratory engineers.

Bases stabilized with chemical and bituminous admixtures are favored in some sections, while in others they are looked upon with disfavor, sometimes because of the increased cost over utilization of untreated natural material and sometimes because of belief that the chemical admixtures are detrimental to future superimposed bituminous mats.

Selection of Aggregates

A comparatively new but extremely important development is the application of the study of the factors which govern the adhesion of asphalt films to mineral aggregate and fillers and of practical tests for measuring them. Both the mechanical and chemical characteristics of the aggregate and the chemical properties of the constituents of the asphalt influence the degree of adsorption attained. Means are being developed for improving the adhesiveness of available material through the introduction of primers or of mineral powders which themselves increase adhesion or effect base exchange. Laboratory investigation indicates that the phenomena of asphalt adhesion are influenced by changing physical conditions and by increasing age of the aggregate to the possible extent of converting them from hydrophilic to hydrophobic or the reverse.

The standard tests for hardness and durability of the coarse particles of the aggregate are being continued, but the acceptance requirements are less rigid. Contrasting with this, the quality of the fines, including admixed fillers, are now subjected to increasingly exacting scrutiny, the ordinary soil tests being supplemented by determinations of performance when subjected to conditions simulating those of actual service. The most popular of these determinations are the swell, water-asphalt preferential and apshalt stripping tests, which indicate the preference of the aggregate for water or for asphalt. However, exact procedures for tests of this nature are debatable and are still in a state of development.

The natural cementing value of fillers for bituminous mixtures, as well as of the fine constituents of base courses, continue to receive attention, an interesting fact here being that indications of cohesion are considered by some as desirable and by others as cause for rejection. However, the acceptance of cementicious material appears to be confined to the arid and semiarid regions.

Selection of Bituminous Materials

The merits of the different grades of bituminous materials are, of course, productive of more discussion than any other subject. Opinions on this point are varied and positive with the majority favoring softer asphalts in pavements and cutback asphalts in the lower type mixtures. There is an increasing tendency, however, to question the use of cutbacks in view of the excellent results often obtained by the cheaper slow-curing grades. The proponents of the trend toward softer asphalts are convinced that the oxidation and hardening that takes place during weathering of the pavement brings about a brittleness that causes failures of the surface through its inability to follow minor movements of the base.

The results of studies to determine by the use of accelerated tests the susceptibility of asphalt to change under conditions of weathering, are being applied to construction in various ways, one of the most important being a tendency toward lowering of the mixing temperature. An interesting construction compromise is involved—how can we heat high enough to deliver a mixture to the road in a workable condition without appreciably altering the asphalt?

Design of Bituminous Mats

The difference of opinion as to the relative merits of the voids-ratio and surface area principles for determining the correct proportions of bituminous material in mixtures continues, with the majority using a combination of the two methods and a few relying entirely on the judgment of an experienced engineer. Also, some express a preference for designing for the maximum permissible amount of asphalt and some for a lean mixture topped with a heavy seal coat.

Considerable discussion relates to the merits of open-graded versus dense-graded mixtures, the latter made nonskid by the application of a chip-covered seal coat, with hybrid types being reported from many sections. The conclusion is reached that density is not in itself important but is significant only as it affects permeability, flexibility, and stability. Some writers now favor maximum flexibility of bituminous mats even at the expense of stability so long as the latter is kept above a reasonable minimum limit.

Although the Hubbard-Field extrusion machine is still relied on extensively for measuring the stability of mixtures, it is recognized that stability is supplied by a combination of two fundamental properties, one being frictional resistance between the aggregate particles, and the other frictional resistance, or cohesion of the films of bituminous binder. Hveem has developed a Stabilometer which measures internal friction of the mixture and a Cohesiometer which measures its cohesion. Also, several states have installed circular track testing devices for trying out the serviceability of bituminous mixtures under controlled conditions of moisture, temperature and loading.

In addition to the foregoing highlights, the desirability of extending base courses and prime or seal coats to the full width of the roadbed, the relation between the thicknesses of bituminous mats and the types of base courses supporting them, arguments for and against thickening the edges of mats, the effects of building earth shoulders to the level of the mats and many other points are discussed in the excellent papers reviewed.

More detailed analyses of these papers have been prepared by other committee members as follows:

''Design of Subgrades and of Base Courses and Selection of Aggregates'' by Norman W. McLeod.

''Selection of Bituminous Materials and Design of Bituminous Mats'' by J. E. Buchanan.

Developments in Fundamentals of Bituminous Construction

A Review of Fundamentals in Selection of Bituminous Materials and Design of Bituminous Mats

By

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This portion of the review of developments in the fundamentals of bituminous construction is confined to a summary of the outstanding points contained in 21 papers. It is further restricted to consideration of items related to selection of bituminous materials and design of bituminous mats. It has been intended to represent all views accurately, but if inadvertently this has not been done it is hoped that rectification and clarification will result during subsequent discussions.

The unanimously expressed necessity for an adequate and stable foundation under any and all highway surfaces has been covered generally by Benedict and more specifically by McLeod, and this summary is not concerned with foundation fundamentals.

TERMINOLOGY

The terminology of bituminous construction is indeed confusing, and the need for standardized terminology is very apparent when one is concerned with a review of technical papers from the area represented at this conference. This was expressed by Hveem of California as follows: ''If all pavements composed of mineral aggregate bound together with some asphaltic product were considered under the one heading of bituminous mixtures, I do not doubt that we would have fewer differences of opinion as to what constitutes fundamentals.''

For the purpose of organizing this discussion the following terms are defined:

Aggregates

Coarse Aggregate—Aggregate containing particles larger than ¼ in.

Fine Aggregate—Aggregate containing particles smaller than ¼ in.

Macadam Aggregate—A course aggregate consisting of fragments of substantially one size or a limited range of sizes the smallest of which is ¼ in.

Graded Aggregate—Aggregate containing proportions of particles of all sizes from the maximum size to dust.

Open-Graded Aggregate—A graded aggregate with a limited proportion of particles passing No. 10 sieve and not more than 5 per cent passing No. 200 sieve.

Dense-Graded Aggregate—A graded aggregate with a continuous representation of all particle sizes from the maximum size to dust, and containing between 5 and 15 per cent passing No. 200 sieve.

Bituminous Surfaces

Surface Treatment—Any bituminous surface which has a final thickness less than one inch.

Pavement—Any bituminous surface which has a final thickness greater than one inch.

SELECTION OF BITUMINOUS MATERIALS

Influence of Aggregate

The problem of selection of bituminous materials is inseparably related to aggregate gradation which in turn is influenced by local preference or by the nature of available materials. Aggregate grading is important only as one of the factors in a complete design. There does not appear to be any basis for arbitrarily selecting one gradation over another since all types of grading have been successfully employed. This review will, therefore, summarize reported practices in terms of gradations used or preferred by the different provinces and states.

When dense-graded aggregate is specified the preference is for SC or MC materials for roadmix, and MC's or soft asphalt cements for plantmix. For example, in describing Kansas work, Nuss indicates a preference for dense-graded aggregate, and Benson emphasizes dust or filler preferences to produce the required dense grading. Benson and Johnson report that under these conditions MC's have gradually replaced SC's, but other papers from the same state report that recent research indicates that the supposed superiority of MC's over SC's as to serviceability is to be seriously questioned. Phillips, Russell and Lloyd of Wyoming state that although MC-2 and MC-3 have practically become standard, it is now being realized that SC-3 may be more desirable under some prevailing conditions, and that there is a tendency to return to the use of SC's. Renewed interest in SC-3 has been occasioned by the nominal maintenance costs of some projects on good foundations which have been in service 8 to 10 years.

For open-graded aggregate, as defined above, MC or RC products are generally employed. Smith and Finkbiner of Oregon give detailed descriptions of an open-graded RC-4 plantmix and an RC-3 roadmix using somewhat open-graded screened natural gravel. Smith believes that MC-2 has no place in Oregon road construction, yet one of the advantages enumerated for MC's by Benson of Kansas is its adaptability to open-graded mixes. Wyoming reports that the use of MC with open-graded aggregate is being studied.

Retread or macadam aggregate mixes utilize RC's, emulsified asphalt or tar. Runnals describes retread practice in Vermont using either tar or RC-3. Benson and Johnson of Kansas state that MC mixes employing macadam aggregate failed and have been abandoned in favor of dense-graded types.

Penetration macadam is widely used in Oregon because aggregate suited to this type of construction generally abounds, and Smith states that "all penetration work is based upon hot asphalt as neither cutbacks nor emulsions have shown comparable ability to hold aggregate and have been discarded (in penetration macadam construction) except for prime or seal coats in special instances or patching during the winter season.''

Influence of Construction and Maintenance Methods

A successful solution to the problem of selection of bituminous material cannot ignore the influence of construction methods nor of maintenance methods. For example, Smith explains the selection of asphaltic materials used in Oregon thus, ''The type of bituminous surface is closely correlated to the method of maintenance, and bituminous construction to be successful must have its design based upon the type of maintenance to be employed. In Oregon the maintenance of bituminous surfaces is based upon the use of Extra Gang Hot Plant patching of such character and refinement that the condition of the roadbed is maintained in a state equivalent to its original construction. Every bituminous surface is designed adequate for its traffic, or as a step in stage construction as traffic increases, and no design contemplates reworking or remixing at any future time. This idea, therefore, presupposes that the roadbed and surfacing will be of a stable nature, and every attempt is made to construct the surfacing with adequate thickness and strength.'' Asphaltic materials employed are 120-150 penetration asphalt in penetration macadam pavements and 150-200 penetration asphalt (liquid asphaltic road material 95+) in penetration surface treatments. Roadmix construction using RC-3 is employed in Oregon in those areas where macadam aggregate is not available. It is contended that it is probably easier to roadmix RC-3 with open-graded aggregate (less than 3 per cent passing No. 200 sieve) than it is to mix MC-2 with a dense-graded aggregate.

Another interesting observation reported by Phillips of Wyoming was that MC mixes have been found easier to remix than SC-3 mats, hence they may be maintained by one-man units.

Influence of Weather Condition

It is readily apparent from the papers reviewed that increasing attention is being paid to the selection of bituminous materials to resist weathering and to provide durability. In general the order of preference for bituminous materials to achieve this objective is: (1) asphalt cement (2) RC's (3) MC's (4) SC's.

There are two interesting developments reported that are considered the most important points relating to fundamentals that are presented to this conference by the group of papers reviewed. The first is a consideration of the advisability of using softer asphalts to achieve more durable performance by pavements. There is a definite and unmistakable trend throughout the country toward softer asphalts. The second is an intensive study of bitumen-aggregate adhesion for the purpose of developing methods to aid in selecting bituminous materials to resist moisture and weathering.

Concerning the trend toward softer asphalts, especially in hot-laid pavements, specific indication or mention is made by Covert of Mississippi, Lawson of New Brunswick and Gottlieb of Alabama. Powers presents original and interesting data on hardening of asphalt in Arizona pavements. Asphalt of 56 penetration used in a pavement laid in 1934 was found now to have hardened to 12 penetration. In another pavement the asphalt hardened from 41-58 penetration to 3 penetration since 1923, and still another changed from 57 penetration to 19 penetration in one year. From these data Powers suggests, "—— that asphalts of softer grades can be successfully used, and that they will serve equally as well as the harder grades. Certainly if the usual 40-60 (penetration) range of asphalts is considered to be satisfactory on the basis that they remain in that state, but which we feel they do not for any length of time, there would be no objection to starting with a softer asphalt and attaining that goal at a later date." A field experiment recently constructed by California on U. S. Highway 99 south of Bakersfield in which hot-laid asphaltic concrete was placed using 50-60, 76, 110, 160 and 200-350 (90-95 road oil) penetration asphalts. Progress reports of relative performance and changes in penetrations which may be issued from time to time on this experiment will be valuable contributions. It is also interesting to note that the increasing use in the West of plant mixes using 95+ (150-200 penetration asphalt) and 90-95 (200-350 penertation asphalt) agrees with this trend toward softer asphalts. Another form of this trend was mentioned by Russell who stated that Wyoming is considering the use of a softer asphalt base for MC's. As softer asphalts are used, mixing temperatures may be lowered, which apparently will mean less hardening of asphalt during construction, and will probably provide a greater margin against age hardening and cracking in service.

Concerning bitumen-aggregate adhesion as a factor in selecting bituminous materials, it is generally recognized as being important, but there is less agreement as to how tests shall be made and interpreted. Kansas is working on a thin-film exposure test. Dr. Winterkorn of Missouri comprehensively reviews the present status of the problem and analyses the factors which govern bitumen-aggregate adhesion, test methods, and primers or addition of substances to promote better adhesiveness where needed. He states that since most roads are exposed to the influence of moisture, affinity of aggregate and filler for bitumen has to be compared with that for water. Both Washington and California concur in this opinion. Tremper reports laboratory development of a washing or stripping test. Winterkorn also emphasizes the importance of the chemical character of both aggregate and bitumen, and with regard to the question of asphalts of high or low asphaltene content, he states that asphaltenes are generally appreciated as an important binder constituent with beneficial effect on adhesion. In discussing test methods, such as water-asphalt preferential test, swell test, Hughes' jar test, Nicholson's test and others it is emphasized that test curing comparable to that obtained in service is essential, and that aggregate used in tests should be the same as used on the road. Caution is suggested concerning the use of chemical adhesion tests pending further study. Adhesion is stated, as a rule, to increase with time, and this agrees with the findings reported by Tremper. It is further shown that bonding strength is roughly proportional to consistency, and it follows that better adhesion is obtained with harder asphalts. Highly weathering resistant bitumen should be used in open type pavements, and if not such types should be avoided.

Bitumen-aggregate adhesion factors point toward the desirability of selecting harder asphalts. This agrees with conclusions reached in the field as reported by some states. Oregon uses asphalt cements of 120 to 200 penetration and RC's in preference to MC's or SC's for climatic conditions varying from –50° F. to 110° F. in temperature and from 5 in. to 80 in. annual precipitation. Covert states that "the rainfall in Mississippi averages fifty-five inches per year, which is equally distributed over nine months of the year. Due to this rainfall, a bituminous material that has emulsifiable characteristics has proven unsatisfactory, and as a consequence, the slow-curing and medium-curing cutbacks are not satisfactory. Emulsions are also affected by this rainfall. As the rapid-curing cutbacks and asphalt cements have from past experience proven the best bituminous binders, these are the preferred bitumens.'' Tremper and Stackhouse report a roadmix project on which specifications were changed from SC-2 to MC-2 because there was doubt concerning adhesion between the SC-2 and the aggregate concerned.

DESIGN OF BITUMINOUS SURFACES

Surface Treatments

Considerable use is being made of thin bituminous surfaces by some states, notably Washington, Alabama and Oregon. Other states have definitely rejected this type and prefer thicknesses of two inches or more. For example, Nuss analyzes conditions in Kansas and concludes that no bituminous mat should contain less than 1200 tons of aggregate per mile, and Covert states that in Mississippi the thicker mats show lower maintenance cost. On the other hand, reports from proponents indicate that experience justifies the use of the surface treatments developed and used in their respective states.

Proportioning Mixtures

According to Hveem of California, ''a good pavement should satisfy many requirements, some of which —— (are) —— sufficient stability and freedom from raveling; resistance to weather action, including moisture, heat and cold, oxidation; a non-skid surface to eliminate driving hazards; a tight impermeable surface to protect the subgrade **when necessary**; or sufficient porosity to permit suspiration of ground water when **that** is necessary. The pavement should utilize economically the most available aggregates and lend itself readily to construction of a smooth riding surface with the available equipment.'' This outline of objectives in mixture design and proportioning readily suggests that the problem is not only involved, but also a fruitful field for research and ingenuity. Much investigational work has been done, yet a generally accepted method of mixture design has not been developed, and it is quite likely that since it is a design problem standardization may never be achieved.

Many methods of proportioning bituminous mixtures have been proposed. Some methods are based on maximum density or minimum voids; others are based on surface area by means of formulas or charts in terms of grading; others utilize stability, flexibility and cohesion tests. The array of equations and methods which have been proposed have been summarized many times and will not be repeated. Considering all this development work, however, it is interesting to observe that several states have abandoned all equations and rely entirely on observation and judgment.

Of particular interest to those who hold to the void method of proportioning are some comments by Hveem of California who says, "—— knowing only the voids in a mixture and with no other information, it is not possible to determine the quantity of asphalt binder which will give the best resulst. If the pavement mixture is to be rendered tight or impermeable so that moisture will not readily pass through, the most effective means is to provide a dense-graded mixture in which the **pore sizes** are small enough to prevent the passage of water. I might call attention to the fact that the size of the pores cannot be determined by measuring the void volume."

It must be concluded from these papers that it is generally recognized that stability requirements have been overemphasized at the expense of such other important properties as workability and durability (flexibility and impermeability). Mixture design should aim to achieve an intelligent balance of these characteristics for the service conditions to be met.

Hveem of California in discussing stability states that one property possessed by all masses of granular materials, regardless of size or shape, is some degree of internal friction and mixtures may develop stability regardless of variations in grading. It is also pointed out that frictional resistance between two solid bodies may be lessened by separating them with a film of viscous liquid such as asphalt. A mixture of mineral aggregate and asphaltic binder forms a mass whose deformation characteristics follow neither the laws of friction nor the laws of viscous flow. The difference between stability and instability of asphaltic pavements is the difference between lubricated and unlubricated surfaces. On the basis of these fundamental considerations, California practice utilizes two separate instruments for guidance in arriving at balanced mixture design. One is the Stabilometer which is sensitive primarily to internal friction and the other is called a Cohesiometer which measures primarily the cohesion (viscosity or tensile strength) of a compacted mixture. Having measured pavements in service by both instruments, safe minimum values have been established which govern and guide proposed designs. The theory is held that mixtures should contain as much asphalt as can be tolerated without developing instability in order to obtain durability.

Even though there is now no standard method of proportioning, researches and developments are progressing. States which require aggregate production in accordance with strict and standard specifications may safely rely on judgment and they probably feel the need for design tests less keenly than those which attempt to utilize aggregate as found, which more often than not is every unusual and far from standard. Economies which may be achieved by using native but unusual aggregates are worth considerable effort and study.

Penetration Macadam

Controversies concerning design and proportioning of macadam have not been as intense nor as involved as for mixtures. Smith of Oregon presents detailed procedures and quantities for macadams and surface treatments built by the penetration method which will be found valuable for those interested in this type of work.

Primes and Seals

Accurate data on depth of penetration and performance of primes has been lacking. Stoddard of Iowa presents detailed information on this subject which was obtained by laboratory studies. These studies were planned to determine the effect of aggregate density and moisture content on the penetration of primers and to determine how effectively primers prevent loss of moisture, for example, from stabilized soil bases. It was discovered that SC-2 and TC-2 penetrated soil with normal moisture content better than dry soil, while little difference was noted for MC-2. The most effective subgrade seal was secured with 0.4 gal per sq. yd. of MC-1.

There was comparatively little discussion concerning sealing. Mr. Russell of Wyoming described a special material, RC-1A, which is required for resealing SC-2 mats.

SUMMARY

The following points are listed as being most prominent among the papers reviewed:

1. The chaotic state of terminology needs remedy.

2. There is now a tendency to reconsider the SC's, whereas formerly the trend was entirely toward MC's.
3. There is strong support for all types of aggregate and all types of construction. Aggregate availability, climatic conditions and accumulated experience in the individual states and provinces probably account for this, but at the same time there is every evidence of willingness to change if improvement can be realized.
4. There is a definite trend toward the use of softer asphalt cement, and there is increasing interest in aggregate-bitumen adhesion.
5. While there has been no particular clarification of proportioning methods, the aim of mixture designs is away from maximum stability and toward combined stability, workability and durability (flexibility and impermeability).

Developments in the Fundamentals of Bituminous Construction

REVIEW

OF

DESIGN OF SUBGRADES AND OF BASE COURSES AND SELECTION OF AGGREGATES

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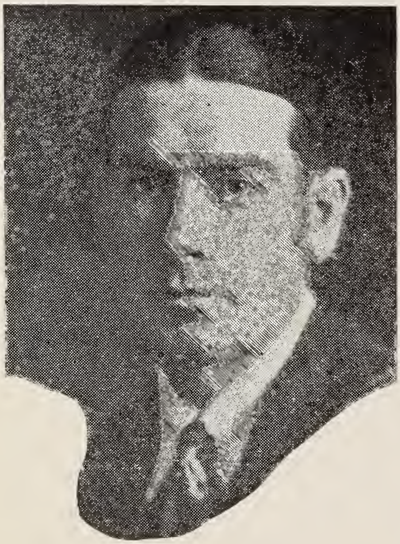

These topics have been very thoroughly discussed at each of the two previous Bituminous Conferences. However, due to the attractive method by means of which information has been gathered for this conference, through the contribution of papers from each state, many interesting and often controversial opinions have been expressed. These variations in opinion very often reflect the variations in topography and climate of the areas, from which the papers have been contributed. It is the purpose of this paper to classify these opinions under the various headings which follow together with whatever other information appears pertinent.

Because of the abundance of material in the many excellent papers contributed it is impossible to do justice to any one paper in this short review.

(a) DESIGN OF SUBGRADE

(1) Applications of Soil Mechanics

It now appears to be universally recognized that the ability of a well designed flexible surface to resist the mechanical forces tending to bring about its failure, depends very largely on the ability of the subgrade to absorb the load transmitted to it without failure; that is the bearing capacity limit of the subgrade must not be exceeded. This idea is expressed in various forms in practically every paper discussing the relationship between mat thickness, including base course, and the character of the subgrade.

A number of formulas which have been suggested for use in determining the mat thickness in the design of flexible surfaces have been discussed at previous conferences. These have been considered to be based on assumptions which are too questionable for general acceptance.

Mr. A. B. Nuss of Kansas states that the subgrade should be designed to carry the full wheel load when the bituminous mat is less than two inches thick.

In a paper on the ''Design of Flexible Surfaces'' by Professor W. S. Housel, Research Consultant for the Michigan State Highway Department, at the twenty-third Annual Highway Conference at the University of Michigan last spring, it is concluded from a review of existing literature on pressure distribution, that the full surface pressure is transmitted to the subgrade unless the thickness of the mat is greater than one quarter of the width of the contact area. Professor Housel's paper should be carefully read and studied by every engineer who has to design flexible surfaces. The paper is limited to a consideration of subgrades of cohesive soils which in actual practice are most troublesome. The paper concludes with design curves showing the relationship between mat thickness for probable ranges of load, subgrade bearing capacity, tire inflation pressure, and shearing resistance of the bituminous mat.

Professor Housel considers impact forces to be negligible compared with static load.

Due to inability to control the moisture content of the subgrade, which has a large effect on the safe load the subgrade will carry, bearing capacity tests have not been seriously considered to date by designing engineers. The tendency is still to correlate subgrade treatment and thickness of base course required, on the basis of the behavior of other similar subgrades under similar conditions on other projects.

(2) Soil Surveys

A very interesting paper was contributed by Rockwell Smith and C .C. Hansen from Minnesota which shows the value of extensive soil surveys previous to bituminous construction.

Localized soil surveys are made to establish treatment for localized defective areas in the subgrade.

General soil surveys make it possible to obtain uniform subgrade conditions by the selection of soils in grading operations.

Due to subgrade treatments resulting from these soil surveys it has been possible to decrease appreciably the base thickness formerly thought necessary in Minnesota. From six to nine inches is now deemed sufficient where one foot was required two or three years ago.

The practice of compacting the upper foot or two of a new grade in shallow layers at optimum moisture content with a sheep's foot roller, very greatly increases the bearing capacity of the subgrade and its resistance to water and frost action.

J. R. Phillips states that soil surveys are made on questionable locations in Wyoming.

Mr. A. B. Nuss of Kansas believes that a soils engineer with Proctor and other equipment should be on every stabilization project.

The value of the soils engineer for subgrade and base course design is only beginning to be appreciated in most areas.

(3) Soil Classification

The U. S. Bureau of Public Roads classification of soils is in very common use. At least several states find it convenient to use the U. S. Bureau of Soils classification either exclusive of or in conjunction with the former system of classification for soils in groups A-4 to A-8. It is claimed that the name given to any soil by this latter classification more clearly defines the characteristics of the soil as to capillarity, ease of drainage, etc., to engineers acquainted with the area than to describe it as an A-6, etc., soil. The U. S. Bureau of Public Roads classification of A-1, A-2, and A-3 appears to be amply descriptive as far as the highway engineer is concerned for those soils which fall into these groups.

(4) Subgrade Stabilization

The various methods for stabilizing subgrades by

(1) the addition of granular to cohesive soils and vice versa,
(2) the addition of bituminous materials,
(3) chemical admixtures,
(4) Portland cement,

have all been described and discussed at previous meetings.

The opinions and procedures given by a number who have contributed papers are therefore appended at this point as being sufficient to promote discussion.

From Kansas, A. B. Nuss, J. R. Benson, and A. W. Johnson, consider that stabilization of all subgrades for bituminous mats results in over design in many cases. Well drained subgrades of silt and sand loams under bituminous mats are expected to carry present-day traffic in Kansas without treatment, while subgrades of clays and clay loams require stabilization. Some silt and loam subgrades have been stabilized with Portland cement, but the writers make no comments on these.

I. E. Russell, J. E. Lloyd, and J. R. Phillips from Wyoming report that fills are compacted in eight-inch layers by wetting and rolling. No base course is provided when the subgrade contains suitable soil.

G. S. Covert, Mississippi, and I. E. Russell, Wyoming, state that heavy clays and plastic soils are removed and replaced with suitable material.

Soil stabilization with emulsified asphalt is used when economically feasible in Mississippi.

C. L. McKesson states that soil stabilization with emulsified asphalts is increasing. In both road-mix and plant-mix emulsion stabilization projects, less water is now being used than was formerly believed necessary, when water was added up to the liquid limit of the soil.

Details of the stabilizing of sandy loam and fine silty soils with from 4 to 5% of MC-2 in Nebraska are given by G. F. Briggs.

H. G. Smith of Oregon prefers stabilization of soils with gravel to their stabilization with bituminous or chemical admixtures, believing the chemicals used will leach out, and the bitumen lead to subsequent movement unless carefully controlled.

W. J. Lawson, New Brunswick, Canada, describes the use of tile drains for stabilizing the subgrade. Five hundred thousand feet of tile have been laid. A certain amount of frost action still occurs in spite of the careful tiling.

The stabilization of soils through the medium of base exchange, or the swapping of ions as it has been somewhat derisively termed by some, has possibilities for minimizing the effect of water on soils which do not appear to have been fully realized. Future research will undoubtedly make considerable advances in this direction.

(b) DESIGN OF BASE COURSES

The type of base course favored still depends largely on the area in which it is to be constructed, and ranges from the heavy ballast type of base course of the Rocky Mountain States, to the thin, well stabilized, gravel bases of the plains.

H. G. Smith from Oregon prefers a stabilized base six to ten inches thick, using a ballast of quarry stone, talus, or gravel. No minus 200 mesh material is permitted in the filler.

Oregon's theory of design calls for adequate base support since reworking of the bituminous mat at some later time is not contemplated.

A warning is sounded against present tendencies to use clay stabilized gravel bases, particularly when deliquescent salts such as calcium chloride are present, because of the detrimental effect of capillary water.

J. L. Stackhouse from Washington states that the abundance of gravel deposits, rock quarries, and talus slides, makes a ten to fourteen inch base course inexpensive, and base stabilization by chemical admixtures, bituminous materials, etc., has not been used. The amounts of these materials used on any location rests upon the judgment of the location engineer. Mat failures have occurred when filler material containing clay has been used in the base course, and sandy fillers with the physical properties of A-1, A-2, and A-3 soils are now specified.

Stabilized gravel bases conforming in general to the specifications of the Calcium Chloride Association are in common use east of the Rocky Mountains.

G. F. Briggs from Nebraska describes gravel type, and sand type stabilized soil mixtures used as base courses.

A. B. Nuss, J. R. Benson, and A. W. Johnson, Kansas, report that clay surfacing six to twelve inches thick, placed on a sand subgrade, and used to support a sand gravel surface for some time, resulted in higher maintenance costs for bituminous mats placed thereon, than for similar mats placed on adjacent sand subgrades.

These writers state however that sands stabilized with clay have been satisfactory bases.

Stabilized gravel bases in Kansas, with salt as admixture, have given fair service. These have apparently not been under bituminous mats.

According to L. Gottlieb a graded earth base course, six to eight inches minimum thickness, constructed in consolidated layers, appears to have sufficient bearing capacity under their three-quarter inch inverted penetration type mats for present day traffic in Alabama.

J. R. Phillips, I. E. Russell, and J. E. Lloyd, Wyoming, state that bases of sufficient thickness, as dictated by experience, are placed where necessary, the thickness varying from no base course at all on suitable subgrades to eighteen inches on very poor gumbo, with an average of five inches. When required, heavy bases of pit-run gravel stabilized with soil binder and water are constructed. A leveling course of stabilized crushed gravel is placed on this. The soil binder is evaluated by the cementation test on the minus 10 mesh portion. The amount of clay binder is kept low in the leveling course under the bituminous mat.

In New Brunswick, Canada, according to W. J. Lawson, a four-inch gravel base consolidated by traffic serves as a foundation course for a three-inch bituminous concrete mat.

In Saskatchewan, a three-inch stabilized gravel mat over a gumbo subgrade with a P. I. of 100 has demonstrated over a two-year period its ability to function as a base course. It has come through two spring break-ups without a single break when adjacent loose gravel sections have been nearly impassable. This was surfaced with a bituminous mat this year.

A six-mile three-inch stabilized gravel mat was constructed over a subgrade of the same type of soil this year using sodium chloride, calcium chloride, and sodium sulphate as chemical admixtures. While it is too early for definite conclusions, the sodium sulphate section, appears to be the most durable and most satisfactory at the present time.

A. E. Stoddard from Iowa reports some research carried out on stabilized soil aggregate mixtures.

He found that,

(1) the moisture content of the stabilized base course was very much less than that of the subgrade on which it was laid.

(2) Stabilized gravel mixtures show practically zero flexural strength at the optimum moisture content, but develop strength as the moisture content is decreased.

(3) Moisture contents in the bases ranged from 34 to 90% of the estimated optimum for the mixtures.

The important conclusion reached, is that some beam strength can apparently be developed in stabilized soil aggregate mixtures if the moisture content can be reduced below 50% of the optimum.

Mr. Stoddard suggests that priming the subgrade below the stabilized gravel course may contribute to the maintenance of a low moisture content in the base course. 0.4 gallon per square yard was the most effective primer tried insofar as prevention of evaporatoin is concerned.

Mr. Briggs from Nebraska also suggests that stabilized gravel base courses may be considered to be semi-rigid pavements, and that these bases only two or three inches in thickness with a double armor coat treatment which have proven highly satisfactory in Nebraska, represent the ultimate in economy in pavement construction.

A statement by I. E. Russell, Wyoming, to the effect that motor vehicle speeds in the future will not be increased and may even be reduced below present speeds, should develop some discussion.

(c) SELECTION OF AGGREGATES

In the selection of aggregates the trend is still towards the greatest possible use of local materials. The rigidity of specification requirements is very largely proportional to the wealth of the area, or to the availability of specification materials, where the aggregates are to be used. Several papars report the lifting of rigid specification requirements, within limits, in order to permit the use of local aggregates which would otherwise be excluded.

G. F. Briggs from Nebraska describes an interesting set of four standard specifications for aggregates for bituminous mats in which the maximum size of aggregate decreases successively. The loss of stability due to the decreasing quantities of coarse aggregate is compensated for by increasing the quantities of minus 200 mesh filler. These four standard gradations make it possible to use available local materials.

Dense-graded aggregates are generally preferred to open gradations in order to protect the subgrade from surface water, to protect the bituminous binders from the weathering of water and air, and partly because it is generally considered that these give greater stability.

N. M. Finkbiner from Oregon, describes the use of open graded plant and road mixes. The choice of aggregates for these depends on the assumption that either quite open or tightly closed mixes should be used, since danger from freezing is much increased in a semi-tight mix which does not contain sufficient outlets for the expansion of water when forming ice. The open graded mix is expected to remain skid-proof over a period of years.

J. R. Benson and A. W. Johnson of Kansas report generally unsatisfactory results when open graded mixtures were placed on old mats and these have given up entirely.

Mr. Benson states that research has shown that from 5 to 15% of the total aggregate must pass the 200 mesh sieve to produce the most satisfactory results. No details of tests leading to this conclusion are given other than that the tests used were stability, swell, and impact.

One of the most important properties required in any pavement is stability and this is very largely dependent on the aggregate used.

A new theory of the internal stability of granular materials, the "arch" theory, has recently been proposed by Professor Housel (A.S.T.M. Proceedings Vol. 36, Part 2, 1936) in which the behavior of granular materials under stress, can be accurately and simply described in terms of elementary arches of particles, in which the ability to sustain vertical pressure is dependent on the horizontal thrusts supplied by adjacent particles in the mass. By this theory the internal stability of granular materials is measured in terms of the angle of pressure transmission as conceived in the stability of the elementary arch, the internal stability increasing as the angle of pressure transmission decreases, and vice versa. The angle of pressure transmission of any granular material is determined by a modification of the California Stabilometer.

An interesting and comprehensive discussion of the fundamental factors affecting the selection of aggregates is contained in a paper by F. N. Hveem, California.

Mr. Hveem points out that since asphalt macadam, sheet asphalt, Warrenite, plant and road mixes, retread, etc., are all capable of carrying considerable traffic without distortion, the fundamental requisites for stability are sufficiently realized in every stable road surface regardless of type. Therefore, stability is not a property which depends on the gradation of the aggregate, consistency of the bitumen, density of the mixture, presence or absence of filler dust, hardness of aggregates, or any other condition or ingredient peculiar to some one type of pavement and not in others.

Stability of a pavement is reduced to two factors, the frictional resistance between the solid particles of mineral aggregate, measured by the California Stabilometer, and the frictional resistance in the films of bituminous binder which can be measured by the Cohesiometer.

Mr. Hveem finds a distinct relationship between low Stabilometer values and unstable pavements. Consequently the basic factor in securing the stability of a bituminous mixture is the maintenance of a high frictional resistance between the aggregate particles.

However, stability is only one required property of a pavement and Mr. Hveem summarizes the important fundamentals which may affect the selection of aggregates as follows,

(1) For the best stability, a harsh crushed stone with some gradation, to be mixed with just sufficient asphalt to give high compaction.

(2) For impermeability, a uniformly graded aggregate with a sufficient quantity of fine sand, fine sand being considered more important in this respect than filler dust.

(3) For non-skid, a large quantity of the maximum size aggregate within the size limits used.

(4) For workability and freedom from segregation, a uniformly graded aggregate.

The remainder of this review is devoted to a consideration of findings concerning the adhesion between mineral aggregates and bituminous materials.

A great many papers make note of the desirability of having the adhesion of the aggregates greater for bitumen than for water, this being one of the principal reasons for the modern trend toward the greater use of cutbacks in most areas.

B. Tremper gives the results of research carried out in Washington on the adhesion between aggregates and bituminous materials. These may be summarized as follows,

(1) When swell and wash tests are used as indicators of adhesion, these give diverse results in many instances.

(2) Various SC-2 California oils showed adhesion differences which were insignificant in comparison with adhesion differences exhibited by various aggregates.

(3) The adhesion of all bitumens improves with age and with heating the aggregate.

(4) Aggregates showing the same initial wash and swell values show different rates of improvement of adhesion during curing.

(5) Adhesion values change with the amount of absorbed and adsorbed water in the aggregate, which is influenced by atmospheric humidity, location in the pit, etc.

(6) The failure of the aggregate to hold to the bitumen occasionally, after the construction of non-skid seal coats, may be attributed to the lag in the development of the full adhesion between the seal aggregate and the bitumen.

(7) The adhesion of aggregates was found to be higher for cutbacks than for SC's.

Dr. Winterkorn of Missouri gives an excellent resume of "The Present State of the Adhesion Problem in Bituminous Road Construction." Only a few of the outstanding points touched on in his paper can be given here.

When adhesion is defined as the resistance to separation of two adjoining materials, it may be due to,

(1) mechanical factors, such as plugs of bitumen which have solidified in the pores of the aggregate.

(2) surface physical phenomena, such as the concentration and molecular weight of the bitumen, and the oriented adsorption of active compounds in the bitumen.

(3) surface chemical phenomena, such as the formation of insoluble compounds by the chemical reaction between the surface of the aggregate and certain active groups in the bituminous material.

Adhesion has been found to increase with increasing consistency of the bitumen, possibly due to the increasing complexity of the molecules.

The chemical and physical composition of the mineral surface has an important effect on the adhesion for bitumens which may be developed, because of chemical reaction with certain compounds in the bitumen, or ability to influence the adsorption and orientation at the mineral surface of the molecules in the bitumen possessing dipole moments.

Due to the complexity of bituminous materials, there is a time lag in the development of the full adhesion of a bitumen for an aggregate, during which the active compounds in the bitumen are migrating to the mineral surfaces. (Some of Mr. Tremper's findings could be explained on this basis).

The difference between energy of adhesion and wettability of bitumens for mineral surfaces is pointed out, and how this should affect design.

A critical discussion of the many various tests which have been suggested for determining the adhesion between aggregates and bitumens is given.

The surfaces of minerals can be made to have a higher adhesion for bitumens by

(1) precoating with certain polar organic substances,
(2) such mineral coatings as lime, Portland cement, iron oxide, etc., for which bitumens have a great affinity,
(3) base exchange.

Dr. Winterkorn believes that enough scientific and practical data have been accumulated by workers on the adhesion problem to enable engineers to design good pavements with bituminous binders.

Conference on Developments in the Fundamentals of Bituminous Construction

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Mr. Benedict: We of the committee take unto ourselves the advice of the professor who urged his students "speak up to be heard, stand up to be seen, and shut up to be appreciated." So the rest of the show is up to you gentlemen. We have attempted in our reviews to summarize briefly the points brought out in the very excellent and more lengthly papers submitted for the conference. We realize we have thrown quite a bit at you in a short while, but practically all the points are ones upon which you have been thinking before you came to the conference. Feel free to bring up any questions you choose; present any proposition you wish; but let's talk these things over.

Mr. Zass:
Arkansas

I would like to ask if there have been any limiting values expressed for the liquid limit and plasticity index of the soil portions of base courses and if a percentage of the colloids in such soil portions bears any relation to the limiting values.

Mr. Benedict: This is a very good point for some of the soils men. The liquid limit, plasticity index and asphalt stripping determinations have become more or less standardized, but your question is whether or not the limiting values are correlated with the percntage of colloids in the materials and just what are suitable limits for plasticity index and liquid limit. Am I right?

Mr. Zass: Yes. What is deemed conservative practice?

Mr. Benedict: Of course, that depends upon the local moisture conditions. Let me say, on behalf of the western portion of the United States, where considerable rainfall occurs, that for bituminous base courses and mixtures the liquid limit is usually confined to 25 and the plasticity index to 6, except that with a plasticity index of 0 a liquid limit as high as 30 is permitted.

Dr. Winterkorn:
Missouri

One aspect of the question involves any possible connection between the percentage of colloids and the physical properties of the materials. The term "colloid" designates only the size of a material, not its physical and chemical character. Therefore, colloids of different origin and from different sources possess different properties. Consequently, if soils come from geographic units alike in climate, topography and geologic structure, a certain connection exists between the amount of colloids and the nature of the soils, as expressed by their consistency limits. If one passes from one soil family to another, a different set of functions is found between the amount of colloids and the different physical properties of the soils. In the tropics, for example, a soil may possess 60 per cent of colloids and still be so porous that almost immediately after a two-inch rain the soil can be easily plowed. Imagine a soil with 60 per cent colloids in the northern United States, and a rain of two inches. Would not somebody get badly stuck if he attempted to plow even a couple of days afterwards. This is to illustrate that there does exist a difference in the physical and chemical character of colloidal soil materials, and that the percentage of colloids can be correlated with definite physical properties only for soils within definite soil regions. Does that answer the question?

Mr. Zass: That answers the question generally.

Mr. Benedict: In this connection is there not a tendency toward too indiscriminate a use of porous, unfilled bases and large, poorly keyed stone which will sink under spring thaw conditions when in contact with clay? Under these conditions a little more care, possibly some additional expenditure for sand-cushioning, bituminous stabilization, or mixing sand into the top of the subgrade might pay big dividends. How is this item being handled in different states?

Mr. Williamson:
Texas

Mr. Chairman, down in Texas we are just getting rid of a term called ''selected material.'' Now, strange to say about that term, after being with the state for five years, I don't know what it means. The trouble, it seems to me, is that the field engineer puts in a little better material if he can find it; if he can't find it, he doesn't put it in. The main trouble there is the fact that we ought to have some definite specifications and, more important than that, better cooperation between the laboratory and the field.

Mr. Benedict:

Thank you, Mr. Williamson. The matter of clay filtration into base courses has certainly been important to us here in the West, particularly in the heavy rainfall areas. I should like very much to know what preventive measures, if any, have been taken by others.

Mr. Harsch:
California

An experience in Idaho might be interesting to these gentlemen. In the Palouse country they have a soil of A-4 type which becomes quite liquid in the presence of water, and the practice has been in that area for years to construct their bases of a macadam rock of say 2 to 4 inches on top of this soil, and then put the materials passing three-quarter inch on top usually as a surfacing. I had an experience in 1920 in the city of Moscow, where on one of the streets they put down 18 inches of this open rock on the soil and covered it up with about 2 inches of surfacing. The next spring there was mud on top of the surfacing. That same year they put four inches of decomposed granite sand on one of the streets with the same soil conditions, and I think that the granite sand is still on top of the soil.

Mr. Benedict:

Thank you, Mr. Harsch. That was a very interesting experience.

Mr. Nuss:
Kansas

Mr. Chairman, one of the papers was quoted a little while ago as saying he would not advise using salt or calcium chloride or sodium hyposulphate due to the effect on the mat. I would like to hear a little more about that, just what effect those admixtures have on a mat.

Mr. Benedict: Mr. Nuss would like to have an expression of experience in connection with the effect of chemical stabilization on superimposed bituminous mats. Michigan has had considerable experience along that line; I wonder if the men from there will discuss this subject.

Prof. Emmons: Michigan There has been no difficulty in applying bituminous surfaces over gravel roads treated with calcium chloride. Over a period of years probably all of Michigan's gravel roads which carry much traffic have been treated with calcium chloride and many later have served as foundations for bituminous surfaces. Michigan is building gravel bases at the present time with calcium chloride in small amounts and oiled mats are being placed over them. Certainly this practice would not be followed if the records of past performance indicated that the procedure is dangerous. As far as calcium chloride is concerned, I don't think it should be feared.

Prof. Lang: Minnesota Minnesota has had about the same experience as Prof. Emmons. We place bituminous surfaces on stabilized bases, and it is quite the common procedure to use calcium chloride as an admixture when the base is laid. Usually they are not surfaced until the next year, though some have been surfaced the same year, and we have yet to see any detrimental effects.

Mr. Benedict: I recall from last year's discussion, Mr. Emmons and Mr. Lang, that even though a short period of time elapsed between the chemical stabilization and construction of a bituminous mat no later difficulty was encountered.

Mr. Shumate: Colorado I would like to ask Mr. Nuss of Kansas if he wouldn't explain to this group some of the work they are doing on subgrade stabilization. I have in mind one job with local material they have down near the Colorado State line. They are doing a good deal of subgrade stabilization by the addition of moisture. In going over the job and talking to the men, I find them obtaining some wonderful results in the work that they are doing. I would like to ask Mr. Nuss if he would tell us about it. This job, Mr. Nuss, is between Syracuse and the State Line on U. S. #50.

Mr. Nuss:
Kansas

That is a new grading job. I might say that that job is more or less stabilizing the soil with moisture. That is about all there is to it. I might say that this moisture is being added up to what we consider optimum moisture and compacting with sheepsfoot rollers. But that is about all we are doing in the line of stabilization. We haven't done much stabilization such as has been discussed here today. But we do have one job going at this time that consists of about 6 inches of stabilization with emulsified asphalt, and the material that is being stabilized is local clay gravel with limestone; the clay gravel has about 20 to 45 per cent of material that will wash out in wash tests, and that is being stabilized by running it through a mixer just like we would a mat. The contractor is contemplating using a Woods Mixer. He hadn't started yet when we left. But on the job you had reference to we aren't doing any stabilization; we are only compacting.

Mr. Shumate:
Colorado

Well, I spoke to the engineer as to the compaction of the fill.

Mr. Nuss:
Kansas

We compact most all of our earthwork. We compact all bituminous or paving jobs. However, if the road is to remain a gravel road for a year or two or more, we do not compact the fill at that time, but anything that is to take a surface such as paving or oil mat is thoroughly compacted.

Mr. Shumate: Colorado
Well, in this particular job the men told me they did not anticipate placing any base course gravel prior to replacing the bituminous mat. Is that true?

Mr. Nuss: Kansas
Well, I might add that in that section of the state we have our lowest rainfall and our soils drain well. It is a sandy soil, and we have had very little trouble with any mats placed on the roads with natural soil bases, so that we contemplate on most of our work out there not spending a lot of money on bases. However, when you come east of there about a hundred miles, then we have a different consideration as to bases. It appears that we will have to have stabilized bases under all of our mats, except the west third which will not need much of a base of any kind due to the nature of the soil, and the low traffic count and low rainfall.

Mr. Benedict: That is all very interesting. Any more comments along that line?

Mr. Stoddard: Iowa
I would like to ask three questions of Mr. Nuss. First, what is the additional cost in your grading operations due to the special moisture control of compacting? Second, when compaction is laid to the full depth of the fill, is that control required for the full depth of the fill? Third, do you know whether or not that density can be retained when those soils are subjected to freezing and thawing?

Mr. Nuss: Kansas
I might say on the cost factor, our total cost has increased so little that it is hardly noticeable. It seems that about the time we came to the compaction of our grades, the contractors were buying a new type of road machinery to cut their road costs, so that the cost of grading was reduced enough to offset the increased cost of compaction, and our records will not

reflect, at this time, any increased cost. However, if we remove that, there would be a reduction, but it would be very slight; I would say 2 cents a cubic yard would be all the difference there would be. It so happens that it wasn't reflected in our total price, inasmuch as the new type of grading equipment used at that time absorbed the difference.

To the second question, yes. I might add that it depends somewhat on the nature of the soil and what the road is to be used for as to how far the fill is compacted. I would say, however, that wherever we are not going to place new pavement, we may not compact over three or four feet of the fill; but if we were going to pave we would compact the fill entirely. In the cuts we remove some of that material and we compact it 12 inches below grade.

Thirdly, I might add this: To data we think that those soils have remained compacted, but we have had three or four years of the driest years Kansas has ever seen, and there has hardly been enough moisture to moisten those fills to a depth where freeznig and thawing would bother. In other words, we have had very little freezing and thawing damage, but we do think it will retain its compaction. However, we can't definitely state that.

Prof. Lang:
Minnesota
I would like to ask Mr. Stoddard if he has any information on his third question.

Mr. Stoddard:
Iowa
The only thing we have to offer is that we have done some experimental work with some soils that were particularly bad, and Mr. Mullis of the Bureau, working in conjunction with us, suggested we attempt to compact those soils in the laboratory. As they were originally compacted, they seem to be incapable of taking up any moisture, but when they were subjected to the action of freezing and thawing they immediately absorbed a large quantity of mois-

ture and lost their stability. Those were only a few special soils. We haven't constructed any field work with that method. I was just wondering if it would be really effective.

Prof. Lang:
Minnesota

How did you get the water in on the freezing and thawing?

Mr. Stoddard:
Iowa

They were first subjected to moisture, then they were subjected to freezing and thawing, and again subjected to moisture. The samples we used were compacted inside a rubber tube so only the upper and lower surfaces were exposed. As first compacted they took on no moisture.

Prof. Lang:
Minnesota

What kind of water was used? When you used capillary action in some instances, how did you get the water? Did you stand a specimen on a wet blotter before you froze it and then let it take up water by capillarity?

Mr. Stoddard:
Iowa

Yes, but it wouldn't take up any water that way. It wouldn't take any water in the first condition other than the moisture content with which it was compacted. After it was frozen and thawed it would take up moisture very rapidly.

Mr. Vail:
Colorado

One of the engineers of the Reclamation Department told me in connection with something like our fills that as far as they could tell in investigating old dams, outside of the top two feet the interior would stay exactly the way it was put in. Outside of just two feet, they would be in the same condition in which they were put in.

Mr. Stoddard:
Iowa

Did you stop to think that they are also the same two feet that are subjected to freezing and thawing?

Mr. Benedict:

I am afraid we will have to ask the construction division for wholesale forgiveness if we continue into their field. Let's leave the discussion of foundations, base courses, etc., and hurry on to some of the other divisions as the time is somewhat limited. The subject of selection of aggregate is a very timely one and can be considered to good advantage. In his paper Tremper of Washington stated that the swell test is not a dependable test of the power of an aggregate to hold asphalt, and considerable doubt has been cast upon the water-asphalt preferential test for this purpose. He suggested for this purpose of modification of the asphalt stripping test that promises a good quantitative measurement of this quality. Has anyone else experimented with measurements of this quality and, in this connection, is it important to use the same grade of asphalt in these determinations as is used in construction? Draper of Mississippi states that RC asphalt will cling to hydrophilic rock. Has anyone any data comparing the adhesive qualities of different types of liquid asphalt, when tested with the same hydrophilic stone?

Mr. Nevitt: Missouri — I noticed in one of the reviews it stated that the various California asphalts had not shown any difference to speak of in the water stripping test, which I would agree with. But we have found that when you go to radically different types of asphalt, far more different in their base characteristics than the general run of Calfiornia materials, there is a decided difference in action of the water stripping test. However, as remarked in that review, the statement that the difference between th aggregates is of far greater magnitude than the difference between the bituminous materials is still correct.

Mr. Tremper: Washington — I would like to make one correction, or rather state that the intent of the paper I prepared was slightly misinterpreted, in that I did not wish to infer in any way that the swell test and water asphalt preferential test were not considered good tests in our laboratory. What we have found is that the stripping test does not always give the same results. We do not wish to state that any of them is superior in our belief. Possibly as experiences go on, we will find that one has advantages over the other. At the present time we do not take that attitude.

Mr. Benedict: Thank you. I did not intend to state that you drew that conclusion, but I know there are cases of doubt as to the accuracy of the tests.

Mr. Hveem:
California

We have been making swell tests for a number of years and water asphalt preferential tests, and I think it is true that in some instances the water asphalt preferential test has to be taken with a considerable grain of salt. The swell test, however, is a very good test, which doesn't mean that it is perfect. For that reason we are contemplating carrying on an investigation as soon as possible in an attempt to devise better tests and more comprehensive methods which will tell us more specifically and dependably what will be expected. But it still remains, as an off-hand estimate, that we don't find a difference of over 5 per cent discrepancy between the swell test, and the results on the road.

There is another test which we are using experimentally, the so-called Riedel-Weber test, developed in Germany by Dr. Walter Riedel. It consists of placing a bituminous mixture in a test tube and boiling with a series of graduated solutions, including distilled water, and various concentrations of sodium carbonate solution. The test appears to be fairly well correlated with the swell test, and can be applied to porous mixtures, which the swell test cannot. The Riedel test is only applicable to the heavier mixtures. It appears to be rather severe for fuel oils and lighter asphaltic oils. Correlation with the swell test is better if we use heavy asphalt. In regard to the statements which were made as to California asphalts, I am positive that they are not borne out by our experiences. We have made it a point to apply tests to samples of all types and find that there are very distinct differences. I think in general that people in other states who buy commercial asphalt from California will probably get a rather selected range of asphalt. We get a lot of things which are probably not found extensively outside the state. It is quite true, however, that the variations in aggregates are much greater than in the asphalt alone.

Prof. Lang:
Minnesota

Some tests made in our laboratory on aggregate indicate somewhat less stripping with cracked asphalts.

Mr. McCoy:
Bureau of Public Roads

Before we get away from the subject of hydrophilic rock, I wonder if we can develop some information on admixtures for correcting hydrophilic properties. We had one job, I am sorry to say, where we didn't run a test on the hydrophilic qualities of the rock and had to go ahead with it. But we found we could decrease the stripping considerably by adding one per cent of hydrated lime. I suggested a similar treatment on another job and was told that while hydrated lime was effective on the first job, it wasn't going to work on the second. I never did get the reason for it, but you might develop some information from the floor on this point.

Mr. Hveem:
California

Supplementing Mr. McCoy's statement, I happened to have the opportunity of making the original tests—the Petrified Forest Project is what you refer to? I had read Dr. Winterkorn's paper in which he had described the use of soap solutions to make bituminous mixtures that would resist moisture. We do not have the background and intimate knowledge of base exchange phenomena which Dr. Winterkorn has, so we merely go ahead and attempt to improve the bad material by putting in a little of this and a little of that and see what happens. In this case, we tried various soap solutions and various types of asphalts. Any soap solution added was detrimental and made the mixture much worse than before. Hydrated lime was much better than the soap, and appeared to correct the tendency of the asphalt to separate from the aggregate in the presence of water. Later, on a job of our own, we had a similar difficulty—the aggregate showing a high swell—so we immediately applied our small bit of knowledge and added hydrated lime. In this case the mixtures were very definitely worse than before. Further work in that case showed that the addition of simple soap solutions was just the thing, although we did not go into it extensively. It was thought to be somewhat too radical to apply in actual construction at the time. It is, however, an interesting example of what may be done as a corrective measure. Perhaps Dr. Winterkorn could clarify that.

Mr. Benedict: That approaches the topic of base exchange about which I have been reading articles by various writers, particularly Dr. Winterkorn. Also Mr. Hogentogler, with the Bureau of Public Roads in Washington, has done considerable work along that line. The subject is highly academic and terrifically big words are used in expressing the principles and findings, but it furnishes a great deal of food for thought and appears to be very practicable. I wonder if Dr. Winterkorn would tell us a little about it.

Dr. Winterkorn: Missouri

The adhesion of bitumen to mineral surfaces appears to be a function of the physical and surface chemical properties of the mineral and of the physical and chemical character of the bitumen. With non-porous minerals their surface-chemical character appears to be most important. This surface-chemical character is, of course, a function of the kind, number, and arrangement of the atoms, molecules and ions on the surface of the mineral and is, therefore, closely connected with its lattice structure. If the ionic components of a mineral surface are easily exchanged for other ions; i. e., if the minerals possess anion or cation exchange capacity, this can be made use of for increasing or decreasing the affinity of the mineral for bitumen. Consequently, one can differentiate between those minerals and affinity of which for bitumen can be changed by ionic exchange and those the affinity of which cannot be changed by ionic treatment. To the former belong feldspar, muscovite, etc., while quartz is pre-eminent in the latter group.

Since the most extensive study on the effect of base exchange was done with soil materials, the results obtained on soils shall be used to illustrate the case. The surface chemical character of a soil is indicated by the chemical character of its clay and colloid fraction, as expressed by the SiO_2-R_2O_3 ($Fe_2O_3+Al_2O_3$) ratio and the amount and kind of available ions. Experiments on six selected soils from the United States and from Argentina demonstrated that the higher the SiO_2–R_2O_3 ratio the smaller is the affinity for bitumen, et vice versa; but also the higher this ratio the greater changes can be expected in affinity to bitumen by ionic exchange. Treatment of soils with eight different ions revealed as best promotors of adhesiveness iron and aluminum ion, as greatest reductor sodium ion. Therefore the affinity for bitumen of mineral materials possessing base exchange capacity can be improved by treatment with iron and aluminum ions; the effect of the bivalent ions is not as well defined as that of the trivalent and the monovalent. Incidentally, the ferric ion appears to possess also a catalytic influence on oxydation and condensation of organic compounds.

With oxydic minerals of the quartz type chemical adhesion of bitumen can hardly be expected since the surface of quartz is made up of big oxygen atoms polarized and rendered inert by the small, but highly charged, silicon ions. If the mineral consists of silion dioxyde but possesses a porous structure mechanical adhesion may be brought about by asphalt plugs extending into the mineral surface. A porous surface may also retain primers like iron-chloride as such or as iron-oxide, thereby improving its affinity for bitumen. If the surface of the quartz mineral is very smooth and non-retaining only two types of treatment promise success. One is the use as primers of molecules of the Pb-soap type (Ruiz) which posses an inherent orienting power more or less independent of the neighboring mineral surface; the other is the synthesizing of artificial resins on the quartzitic surface as developed at the University of Missouri.

More information concerning the effect of exchangeable bases on the affinity of soils for bitumen may be found in a forthcoming report on a co-operative project of the Bureau of Public Roads, the Missouri State Highway Department and the University of Missouri.

Mr. Benedict: Gentlemen, this is really a coming thing and worthy of deep study and careful research. In the utilization of available local aggregates we have all seen cases of stripping of asphalts that could have been prevented by precautions such as the introduction of suitable powdered mineral fillers or of chemicals such as Dr. Winterkorn has outlined.

In the design, or rather correlation, of base course and bituminous mat, flexibility or rigidity is an old argument. To provoke discussion, I should like to submit the proposition that no bituminous surface, however designed—soft or hard asphalt, open or dense grading—will long endure if subjected to continuous flexing of any material amplitude. If we are to depend solely on the bases to carry the load is there need for anything heavier than a bituminous surface treatment? I know from reading articles by Mr. Gray of the Asphalt Institute that he is interested and well informed on this subject, and I imagine that he will have some comments to make.

Mr. Gray:
New York

Mr. Benedict, as you say, that is an old argument, and I don't know whether it will ever be settled. However, I think the discussion that was started this morning is bringing home to all of us the fact that after all the subgrade, the natural mother earth, carries the traffic load. Last summer at the Harvard Soil Conference, Dr. Terzaghi very aptly compared the earth's surface to the human skin as a living, breathing thing and that many procedures which we have carried on as engineers have been just the same as though we had taken a knife and continuously slashed our skin open and let the blood run out. I mean that when we grade a road we often take the raw earth that is underneath and put it up on top of the fill and then try to build a pavement there when that soil must yet go through a curing process of expansion and contraction before it is stable. It is going to break any pavement that we put on top of it. So the very first thing we should do is provide a top layer of soil which has gone through weathering processes and will move the least under changing temperature and moisture conditions. In new grading operations it will pay to salvage all top soil prior to heavy excavation or fill, and then replace it as a uniform layer over the entire road length.

As to further stabilization of subgrade, it doesn't make much difference so long as it is relatively stable during the changing seasons. The principal controlling factor will be economy and availability of material. Having done that, the question arises as to the sort of pavement that is to be put on the surface. That pavement only need be thick enough to resist two forces; one the abrasive forces of traffic, and the other to be sufficiently dense and resistant in shear as to transmit the static load down to the subgrade.

The question does arise, ''Is a blotter treatment sufficient to accomplish this function, provided you have a solid subgrade?'' I think the answer to that is theoretically yes, but practically there must be a minimum depth of surface to take care of any segregated areas, pockets, or areas that are not completely uniform, against undue wear under traffic. Most of the failures that have taken place in surface treatment have been due to minor irregularities in the application of aggregate or else a small area which had been skipped by the distributor when the asphalt was applied. If such an area breaks through, subsequent deterioration is very rapid. I therefore think that in most instances it is safer to have a minimum thickness of around one or two inches of a bituminous mixture to guard against that possibility.

Mr. Benedict: Thank you, Mr. Gray. In reviewing the papers it was very evident that there is a wide difference of opinion on that subject. Many state engineers feel that a bituminous mat less than two or two and one-half inches in thickness is a structural mistake.

Prof. Lang:
Minnesota

I feel that on a large mileage of the roads of the secondary type that it is economical and advisable to put on a thin bituminous treatment. It will take, under maintenance, perhaps a year to iron out the difficulties that Mr. Gray speaks of, but it will yield a surface sufficient to shed the water and take abrasion. Then on that basis you could design the base to a minimum thickness at the lowest cost, realizing that you were going to have some trouble on the surface, but having put a small amount of money into the surface, you can economically do some maintenance. I wouldn't suggest this for heavy traffic roads, but on a large mileage of secondary roads where there is not enough money to make permanent roads, the surface will eventually be improved by maintenance and with time to satisfactorily accommodate the traffic.

Mr. Shumate: Colorado

Apparently in Colorado we have been going into reverse. We started out about ten years ago building a road two and one-half inches thick and later we dropped down to an inch. This year we went back to an inch and one-half of bituminous mat. We have one road in particular that has a two and one-half inch bituminous mat on a fair subgrade. That road has held up quite well, but the most interesting thing we have is a blotter type job built several years ago. It is about eight and one-half miles long. The average traffic count on that road is 2,500 vehicles for a 24-hour period, consisting of about 100 gas tankers in that period. It is an old blotter type job. Last year the total maintenance cost of that eight and one-half miles was $1,432.00. Sometimes I think we are all kind of batty. We sit up nights trying to figure these things out, and then something like that happens. That job was oiled for one reason and one reason only. They were having a fair and the job had been recently completed, and somebody said, ''Let's oil it before this fair starts.'' We didn't have enough equipment to put in a mix job, so we put in a blotter type job, and I'm telling you it is one of the finest roads in Colorado today. Then those we have worried about and fretted over and thought they would be the most perfect things you can imagine, until traffic starts using them, and then we are up against our old problem again.

Mr. Hveem: California

It occurs to me to make a remark. It may or may not be appropriate, but a long time ago I read a fable in which a number of wise men —I believe there were seven—heard about a mysterious animal called an elephant. So they went to see it. The seven men were both wise and blind, and they investigtaed different parts of the animal by touch, one the trunk, one the tail, one the ear, one the tusks, and so on, and each considered his findings and then they got together to determine what was the most remarkable fact about the elephant, and they fell into considerable disagreement. They even came to blows. None of them were wrong. None of them were exactly right, but each one felt that his own findings were correct.

It seems to me that this discussion as to what constitutes a bituminous road is somewhat the same. While we are dealing with the same thing, and I doubt that anyone who reports his observations is very far wrong, but still there is a complete picture which ought to be considered.

I spent a great many years in construction work before I "degenerated" into the laboratory, and I know that it is not uncommon for construction men to feel that the research men love to play with ideas and theories and make simple problems very complicated. Nevertheless, these same construction men have spent a good many years in acquiring engineering knowledge and information, which included a great deal of intricate and involved subjects, complicated mathematics, strength of materials, and they probably did not feel that it was asking too much for the engineer to be well versed in the use of logarithms and trigonometry. Now it is becoming necessary for the highway engineer to go into a great deal of detail concerning the handling of bituminous materials, and I do not believe the research man will ever boil the subject down to a few simple proverbs, formulae, or slogans for the benefit of the construction man. The man who is actually doing the work and applying the knowledge should not shrink from acquiring the necessary detail, must expect to equip himself with technical information to a considerable degree and know a lot about the detailed whys and wherefores if bituminous construction is to be brought up to the standards required for good engineering.

Mr. Gray:
The Asphalt
Institute

I wish to correct what seems to have been a little misunderstanding of my statement on surface thickness. I don't mean to imply that only two or three inches of surface should be put down. What I meant was that if you are building a surface for a heavy traffic road where enough is involved to justify the expenditure, it is probably safer to put in that thickness to begin with than to rely on several surface treatments.

But again you might get back to the statement of the gentleman from Colorado. I have been building asphalt roads for 25 years, and sometimes I think I know less about it than when I began. I will cite one example which may convey what I have in mind. Often times we start with a surface treatment because it will cost less money initially and require the smallest amount of material. In the East the general practice for treatment of new roads is to put down one-half gallon of primer and follow with one quarter to four tenths gallon of either hot or cold asphaltic material. With water bound macadam, it is probably the only thing to do. But with pit run gravel or crusher run stone, and there is a large mileage of such types, it is my opinion that you can consolidate such a surface that as a mxiture better than you can turn it into a surface treatment.

In a recent work in Maryland on gravel, a very excellent mat varying from inch and a quarter to two and one-half inches deep was obtained by ordinary road mix methods using a gallon and one-tenth for the mixing operations and two-tenths of a gallon for seal coat and sand cover. This total is not much greater than would have been used for an original surface treatment, and experience demonstrates that the greater depth is far less likely to pothole and ravel than the thinner surface treatment.

Mr. Shumate: Colorado

Before I am committed for high treason, I would like to clarify some of the statements I made in this respect. In Colorado we have a great deal of money to spend, and it has to be spent right away. We have a big bond issue that was passed last year, and we received considerable PWA money from the Government. The bituminous mats we are putting down may be fooling somebody, but we are not fooling ourselves. As you know, Colorado is considered one of the semi-arid states. In fact, the eastern part of the state is very arid, almost as bad as western Kansas. It is imperative that when we finish a gravel surface road it be built as soon as possible to retain the mineral surfacing. We have been oiling all our roads and putting down bituminous mats one and one-half inches in thickness.

We feel that it is money well spent, even though it will eventually be improved at a later date. We are doing a cheap job and we are getting some excellent results. Later we will compact and build those surfaces up to a higher standard. Our chief is well lined up on his program. He knows just what he wants to do, and those of you who have traveled our roads will agree that we are getting a pretty good job. We are not holding this work up as a finished job.

Mr. Benedict: I am sorry to be a damper on this very interesting and informative discussion, but the time allotted to us is practically gone. There are, however, two points in particular which were brought to our attention by the papers reviewed and which I should like to call to your attention. They are these: Many engineers are expressing a preference for SC oils and others for MC oils for use under the same conditions. Some in the past have changed from SC to MC grades and are now going back to the SC's. In other words, experience in the use of these two groups of grades is not consistent.

The other point that was brought out, particularly by Powers of Arizona is that asphalts in asphaltic concrete pavements undergo a progressive hardening that eventually results in extreme brittleness of the mat. He reported that penetrations of asphalts recovered by the Abson method of extraction had lowered from an original of 45 to about 6 after several years' use, with one showing a drop of from 60 to 20 penetration after less than one year.

May I suggest that these points with others be considered during the informal, individual discussions that help to make a meeting of this sort so valuable.

Thank you for your interest and active participation in the subject of fundamentals.

Papers Prepared

on

Developments in Fundamentals

of

Bituminous Construction

for

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Studies of Stabilized Soil-Aggregate Mixtures

By

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Since 1930, Iowa has been constructing bituminous surfaced roads. The earlier projects were more of an experimental nature and contained sections of various thickness with different types of bitumen. Prior to 1934, these surfaces were placed on existing gravel or stone surfaced roads. The most evident weakness of all these early sections was inadequate subgrade support. In 1934, some surfaces were constructed with stabilized gravel bases. These sections were thinner than we now consider standard, but the improvement in supporting power of the surfaces was immediately noticeable. Consequently, bases have been prepared for nearly all recent construction.

In construction of stabilized bases we have followed the practices recommended by the Calcium Chloride Association who were fundamental in popularizing this type of construction. These recommendations included gradation of particle size, character of binder soil, plasticity index, etc.

Design theories for bituminous surfaces rely on transmission of the load from the road surface to the subgrade, through a conically shaped section usually with side slopes of 45°. No information was available from work of the Calcium Chloride Engineers to indicate the supporting power of stabilized surfaces, except from their action under traffic. Nor was there any information as to how these surfaces would react when covered with a bituminous surface.

In 1935 when the Materials Department of the Iowa Highway Commission began a laboratory investigation of stabilized soil aggregate mixtures, it was but natural that we applied to this work, test methods which we had found effective in studies of Portland Cement concrete. The first work included a study of density and strength as affected by moisture content of the soil aggregate mixtures.

Six soils were selected which represented the general range of types available in Iowa. These were combined with granular material conveniently available in a local pit near Ames. The analysis of various soils and sand are found in Table I. Since the size of specimen to be examined was small, only that portion of the gravel passing the No. 4 sieve was used in the mixture. For the preliminary tests, the soils and sand were proportioned by weight, using 10, 15 and 20 parts of soil for 100 parts of sand. Analysis of various mixtures will be found in Table No. II.

The soils were brought to an air dried condition, pulverized by passing them through a laboratory hammer mill and screened through a No. 40 sieve. In the operation it was noticeable that soils with low plasticity indexes pulverized easily with one pass, while those with high plasticity indexes required two or three passes through the hammer mill to get them pulverized.

TABLE NO. I

Mechanical Analysis and Subgrade Soil Constants
of the Various Soils and the Sand Portion of the Pit Run Material

Sieve No. (U. S. Standard Series	Particle Size Milli-meters	Soil—Research Numbers and Laboratory Numbers									Sand
		#1 (AAD6-1)	#2 (AAD5-380)	#3 (AAD5-381)	#4 (AAD5-382)	#5 (AAD5-387)	#6 (AAD6-17)	#7 (AAD6-18)	#8 (AAD6-19)	#9 (AAD6-36)	No. A (AAD6-6
#4	4.760	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
#10	2.000	100.0	99.9	100.0	100.0	100.0	100.0	100.0	100.0	100.0	84.0
#40	0.420	100.0	95.6	100.0	100.0	100.0	92.2	100.0	100.0	100.0	40.8
#50	0.295	100.0	93.6	100.0	100.0	100.0	75.5	99.0	100.0	99.0	24.5
#100	0.147	99.6	88.1	100.0	100.0	100.0	72.5	88.0	100.0	98.0	8.6
#200	0.074	98.0	85.7	99.0	99.0	98.0	70.6	83.0	99.0	95.7	7.0
#270	0.050	97.6	83.9	98.0	98.0	96.0	68.7	80.0	97.0	94.7	6.2
....	0.005	9.1	27.8	51.0	33.0	66.0	10.2	8.5	25.4	60.4	2.5
....	0.001	2.0	12.4	16.0	14.0	19.0	4.7	4.5	13.4	31.4	0.4
Liquid Limit		32.4	42.8	79.9	56.8	94.9	50.4	41.0	43.9	49.4	Unable to Determine
Plastic Limit		21.3	16.1	26.4	21.5	29.4	20.6	15.6	19.5	17.9	
Plasticity Index		11.1	26.7	53.5	35.3	65.5	29.8	25.4	24.4	31.5	
Field Moisture Equivalent		25.6	26.1	46.1	33.7	43.5	28.2	22.1	23.9	....	
Lineal Shrinkage		2.9%	6.8%	11.5%	8.3%	9.4%	7.0%	4.5%	4.9%	....	....

SOIL CLASSIFICATION

1. Subsoil of Knox Silt Loam
2. Subsoil of Shelby Loam
3. Subsoil of Wabash Silt Loam
4. Subsoil of Waukesha Silt Loam
5. Subsoil of Lamure Silty Clay
6. Subsoil of Wabash Silt Loam
7. Subsoil of Bremer Silt Loam
8. Subsoil of Clinton Silt Loam
9. Unweathered Argillaceous Shale—Pennsylvania Age.

TABLE II

Mechanical Analysis of Various Mixtures of Gravel (Sand) and Soil Together With Physical Characteristics of Material Passing No. 40 Screen

Soil	Per cent	PERCENT PASSING Sieve Number and Opening—MM.									Physical Characteristics of Material Passing No. 40 Screen				
No.	soil	#4	#10	#40	#50	#100	#200	#270	....	....	Lig.	Plas.	Plas.	F.mois.	%Lin.
		4.76	2.00	.420	.295	.147	.074	.050	.005	.001	Lmt.	Lmt.	Index	Equiv.	Shrink
1	10	100.0	85.4	46.3	31.4	16.9	15.3	14.4	3.1	0.55	15.6	12.6	3.0	13.8	0.4
	15	100.0	86.1	48.6	34.4	20.6	18.9	18.1	3.4	0.56	17.1	10.5	6.6	13.5	1.0
	20	100.0	86.7	50.7	37.1	23.8	22.2	21.5	3.6	0.63	17.7	11.1	6.6	14.1	1.0
2	10	100.0	85.4	46.3	31.2	16.2	14.6	13.6	4.9	1.6	15.8	11.6	4.2	13.0	0.8
	15	100.0	86.1	48.6	34.1	19.6	17.9	16.9	6.0	2.0	19.0	10.8	8.2	12.8	1.3
	20	100.0	86.7	50.7	36.8	22.6	20.8	19.9	7.0	2.5	20.4	9.6	10.8	12.5	1.8
3	10	100.0	85.4	46.3	31.4	16.9	15.4	14.5	6.9	1.9	23.2	11.4	11.8	13.7	1.7
	15	100.0	86.1	48.6	34.4	20.6	19.1	18.3	8.9	2.4	29.4	12.7	16.7	15.8	3.5
	20	100.0	86.7	50.7	37.1	23.9	22.3	21.6	10.6	3.0	33.1	12.0	21.1	17.6	4.2
4	10	100.0	85.4	46.3	31.4	16.9	15.4	14.5	5.3	1.7	19.8	10.5	9.3	14.5	2.4
	15	100.0	86.1	48.6	34.4	20.6	19.1	18.3	6.5	2.1	23.2	10.3	12.9	15.1	2.7
	20	100.0	86.7	50.7	37.1	23.9	22.3	21.6	7.6	2.6	26.2	11.5	14.7	15.1	3.1
5	10	100.0	85.4	46.3	31.4	16.9	15.3	14.3	8.3	2.1	27.9	10.1	17.8	16.8	2.8
	15	100.0	86.1	48.6	34.4	20.6	19.0	18.0	10.9	2.8	34.5	12.5	22.0	18.0	4.2
	20	100.0	86.7	50.7	37.1	23.9	22.2	21.2	13.1	3.5	41.5	14.2	27.3	19.7	4.9
6	10	100.0	85.4	46.3	29.8	15.0	13.4	12.4	3.3	0.85	17.3	10.8	6.5	16.1	0.8
	15	100.0	86.1	48.6	42.0	17.8	16.1	15.2	3.7	0.97	21.6	12.6	9.0	17.7	1.1
	20	100.0	86.7	50.7	34.1	20.3	18.6	17.7	4.0	1.15	23.5	13.2	10.3	18.2	1.9

7	10	100.0	85.4	46.3	31.3	15.8	14.0	12.9	3.1	0.81	17.0	11.1	5.9	14.3	0.6
	15	100.0	86.1	48.6	34.3	19.0	17.0	15.9	3.3	0.9	17.9	11.5	6.4	14.6	1.0
	20	100.0	86.7	50.7	36.9	21.9	19.7	18.6	3.6	1.05	18.1	11.9	6.2	14.8	1.2
8	10	100.0	85.4	46.3	31.4	16.9	15.4	14.4	4.6	1.6	14.9	10.4	4.5	12.0	0.6
	15	100.0	86.1	48.6	34.4	20.6	19.1	18.1	5.5	2.1	17.9	11.6	6.3	13.2	1.2
	20	100.0	86.7	50.7	37.1	23.9	22.3	21.4	6.3	2.5	20.2	10.4	9.8	13.8	1.4
9	10	100.0	85.4	46.3	31.3	16.7	15.1	14.2	7.8	3.3	16.8	10.7	6.1	14.0	2.6
	15	100.0	86.1	48.6	34.3	20.3	18.6	17.8	12.1	4.4	19.1	10.2	6.9	13.3	2.5
	20	100.0	86.7	50.7	36.9	23.6	21.8	21.0	12.2	5.5	20.1	9.7	10.4	14.1	3.3

TABLE III

Weight Proportions and Absolute Volume
of the Materials as Molded Into 2"x2"x14" Beams

Grvl. No. 'Sand'	Soil No.	Per-Cent Soil	Weight Proportion at Basic Water Content			Absolute Volume of Material as Molded in Beams				
			Sand	Soil	Water	Sand	Soil	Density	Water	Air
A	1	10	1.00	0.10	.119	.661	.065	.726	.209	.065
		15	1.00	0.15	.110	.644	.097	.741	.192	.067
		20	1.00	0.20	.125	.623	.123	.746	.208	.046
A	2	10	1.00	0.10	.120	.669	.065	.734	.213	.053
		15	1.00	0.15	.128	.656	.095	.751	.220	.029
		20	1.00	0.20	.133	.633	.125	.758	.224	.018
A	3	10	1.00	0.10	.136	.666	.065	.731	.241	.028
		15	1.00	0.15	.150	.634	.093	.727	.252	.021
		20	1.00	0.20	.158	.595	.116	.711	.250	.039
A	4	10	1.00	0.10	.126	.671	.065	.736	.226	.038
		15	1.00	0.15	.137	.648	.095	.743	.236	.021
		20	1.00	0.20	.142	.622	.089	.711	.234	.055
A	5	10	1.00	0.10	.138	.655	.064	.719	.242	.039
		15	1.00	0.15	.148	.619	.090	.709	.242	.047
		20	1.00	0.20	.167	.585	.114	.699	.259	.042
		20	1.00	0.20	.167	.588	.114	.702	.260	.038
A	6	10	1.00	0.10	.122	.662	.065	.727	.213	.060
		15	1.00	0.15	.133	.642	.095	.737	.229	.034
		20	1.00	0.20	.141	.616	.121	.737	.230	.033
A	7	10	1.00	0.10	.124	.667	.066	.733	.220	.047
		15	1.00	0.15	.130	.653	.096	.749	.226	.025
		20	1.00	0.20	.137	.630	.120	.750	.229	.021
A	8	10	1.00	0.10	.118	.681	.067	.748	.213	.039
		15	1.00	0.15	.125	.662	.098	.760	.220	.020
		20	1.00	0.20	.131	.640	.126	.766	.217	.017
A	9	10	1.00	0.10	.121	.683	.067	.750	.178	.072
		15	1.00	0.15	.128	.662	.098	.750	.226	.014
		20	1.00	0.20	.131	.638	.126	.764	.221	.015

Figure 1.

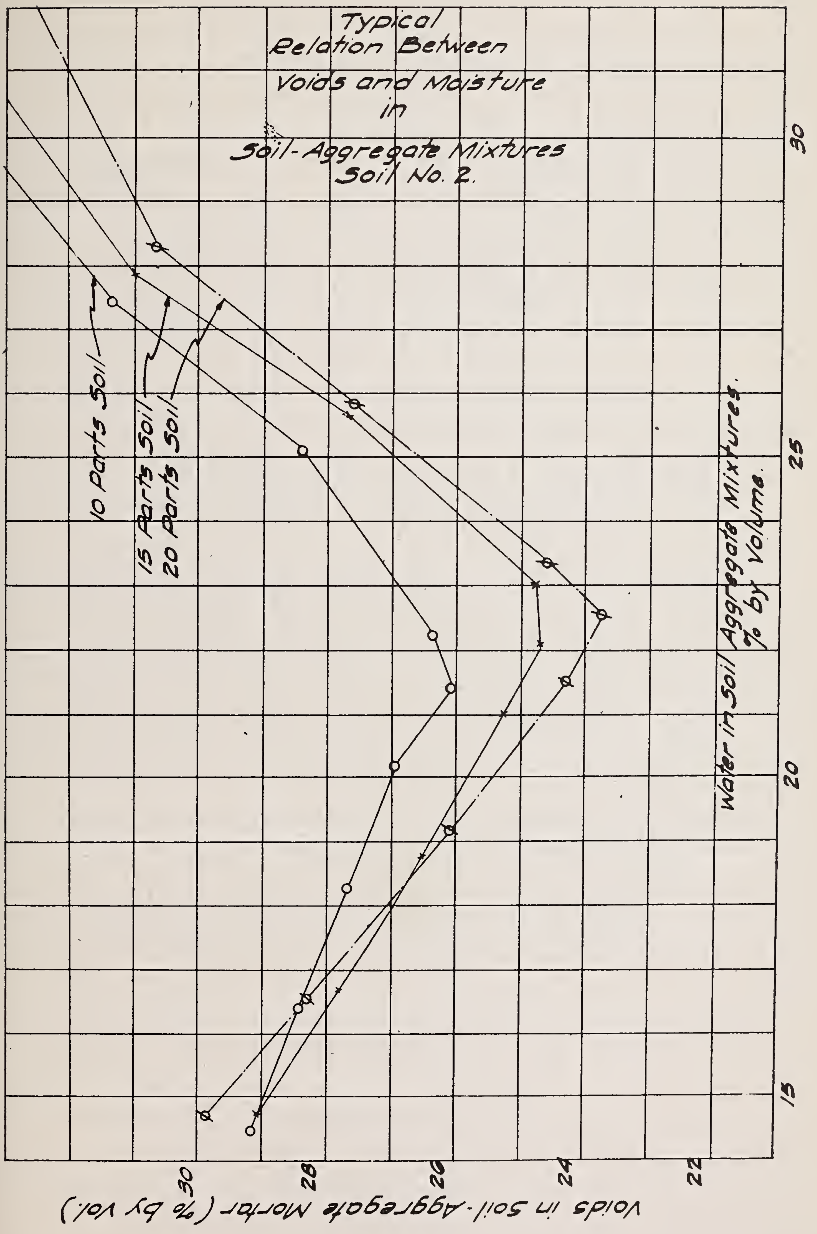
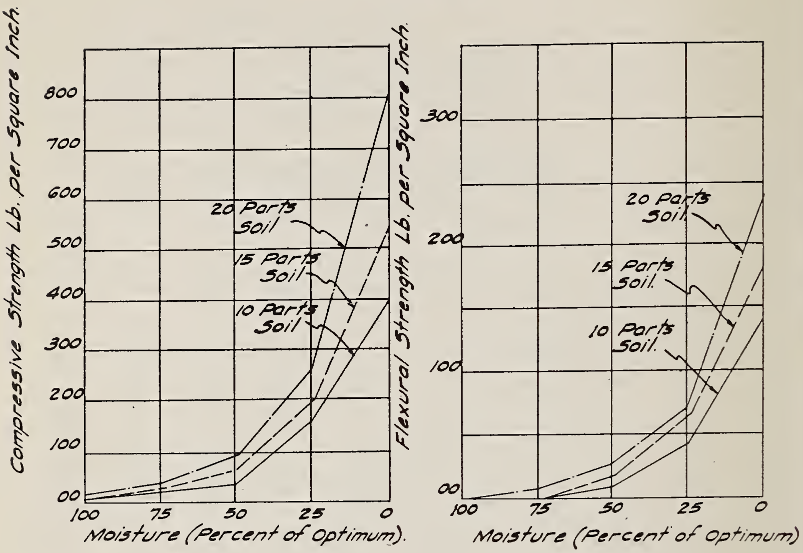

Typical
Relation Between
Voids and Moisture
in
Soil-Aggregate Mixtures
Soil No. 2.
10 Parts Soil
15 Parts Soil
20 Parts Soil
Water in Soil Aggregate Mixtures
% by Volume.
30
25
20
15
Voids in Soil-Aggregate Mortar (% by vol.)
30
28
26
24
22

Figure 2.
Flexural & Compressive Strength
of
Soil Aggregate Mixtures



The density of each soil aggregate mixture was determined for varying percentages of moisture by tamping the mixture in a cylindrical mold 2″x4″ with a solid bottom. Material was placed in five layers of equal quantity of the mixture and each layer tamped 30 times with a spring tamper 7/8″ in diameter. The surface of each layer was roughened slightly before placing the succeeding layer.

The densities of these soil mixtures, followed the same laws as for Portland Cement mortars, in that as the moisture content increased, the voids at first decreased to a point which we would call Basic Water Content or Optimum moisture content, then increased again as the water was increased beyond this point.

The proportions of various ingredients by weight and by absolute volume as used in the beam specimens will be found in Table No. III. It will be noted that at the moisture content which gave minimum voids the densities or proportion of unit volume occupied by solid material, (soil and sand) varied from a minimum of .700 for a mixture of 20% of soil No. 5 to .766 for a mixture containing 20% of soil No. 8. It will also be noted that for mixtures in which soil No. 5 was used, as the percentage of soil increased, the density decreased. In mixtures using soils No. 8 and No. 2 as the percentage of soil increased, the denstiy increased. In some of the mixes the maximum density was reached with only 15 parts of soil. Nearly all of these figures would compare quite favorably with densities obtainable in Portland Cement mortars. Typical void-moisture relationships are shown in curves in Figure 1.

To determine the strength of these soil aggregate mixtures, beams 2″x2″x14″ were cast in metal molds. In making beams, the material was placed in three layers and each layer tamped approximately 150 times with a spring tamper ⅞″ square. This method produced approximately the same density as was obtained in the cylinders. These beams were tested in flexure as simple beams loaded at the ⅓ point. All beams were made with a moisture content which had produced the maximum density. Specimen were tested at optimum moisture content at which they were molded and also at 75, 50, 25 and 0 percent of this moisture content. After testing the specimen as simple beams, the ends of the specimen were broken in compression as modified cubes by the method described by L. H. Koenitzer of Kansas, in the 1934 proceedings of the A.S.T.M. Results of these tests are shown in Table No. IV. Typical relationship between strength of these mixtures in flexure and compression at various percentage of basic or optimum moisture content are shown in Figure 2.

It will be noted for all mixtures, that at the moisture content which is necessary to secure the greatest compaction, the modulus of rupture is practically zero. As this moisture content decreased, the modulus of rupture increases perceptibly. At 50% of the optimum moisture content most of the mixtures began to show some strength. By the time the moisture content was reduced to zero, some of the soil-aggregate mixtures were nearly as strong as Portland Cement mortars. It will be noted that in general, as the proportion of soil in the mixture increased, the strength at zero moisture also increased. This however, was not true for Soil No. 5, but it will be noted that in this mixture as the soil was increased the density of the mixture decreased.

The significance of the strength of these soil aggregate mixtures did not at first impress us greatly because the strength at moisture content at which the mixtures compact well, is very low. However, in 1936, we set out to determine just what was the condition of the stabilized bases which had been laid in

TABLE IV

Average Breaking Strengths at Various Percentages of Original Water

Soil No.	% Soil	Transverse Strength—MC/I Third Pt. Loading—12" Span					Compressive Strength Pounds per Square Inch				
		Water Content at Time of Test—Percent of Original									
		100%	75%	50%	25%	0%	100%	75%	50%	25%	0%
1	10	0.0	0.0	0.0	16.1	61.0	3.3	10.0	39.0	70.0	256.0
	15	0.0	0.0	0.0	18.9	33.0	5.0	24.0	54.0	112.0	360.0
	20	0.0	0.0	13.0	21.9	79.0	8.1	25.0	56.0	108.0	356.0
2	10	0.0	0.0	10.3	*44.0	142.0	5.0	13.0	38.0	159.0	383.0
	15	0.0	0.0	19.4	66.2	189.0	8.6	25.0	64.0	204.0	539.0
	20	0.0	8.7	29.3	75.3	239.0	16.0	39.0	97.0	263.0	789.0
3	10	0.0	7.6	22.0	49.0	244.0	9.5	27.0	60.0	176.0	493.0
	15	0.0	14.8	33.0	51.0	168.0	13.4	39.0	96.0	224.0	583.0
	20	0.0	18.0	34.0	43.0	173.0	21.0	48.0	113.0	212.0	491.0
4	10	0.0	0.0	14.0	32.4	149.0	5.9	19.0	46.0	123.0	399.0
	15	0.0	5.7	18.0	49.0	184.0	13.0	28.0	75.0	168.0	511.0
	20	0.0	11.0	30.0	55.0	176.0	15.0	45.0	91.0	246.0	648.0
5	5	0.0	0.0	9.0	30.0	119.0	3.9	9.0	32.0	68.0	267.0
	10	0.0	10.0	22.3	46.3	123.0	9.6	33.0	84.0	218.0	597.0
	15	0.0	12.3	23.5	36.1	92.0	13.0	41.0	107.0	208.0	461.0
	20	0.0	16.0	38.0	33.0	82.0	12.0	43.0	121.0	185.0	400.0
	20	0.0	24.0	35.0	36.0	90.0	15.0	52.0	105.0	195.0	426.0

6	10	0.0	0.0	0.0	18.0	81.0	6.4	11.0	20.0	71.0	209 0
	15	0.0	0.0	10.0	21.0	87.0	10.0	17.0	37.0	73.0	211.0
	20	0.0	0.0	15.0	35.0	103.0	12.0	24.0	55.0	100.0	303.0
7	10	0.0	0.0	0.0	19.0	102.0	4.6	9.6	18.0	56.0	234.0
	15	0.0	0.0	10.0	31.0	164.0	7.5	16.0	30.0	88.0	328.0
	20	0.0	0.0	10.0	45.0	182.0	9.0	18.0	36.0	116.0	349.0
8	10	0.0	0.0	0.0	23.0	113.0	5.0	11.0	24.0	67.0	219.0
	15	0.0	0.0	9.1	35.0	150.0	9.0	16.0	35.0	95.0	294.0
	20	0.0	0.0	19.0	70.0	189.0	14.0	33.0	67.0	199.0	500.0
9	10	0.0	0.0	17.0	26.0	101.0	5.0	16.0	48.0	66.0	250.0
	15	0.0	13.0	23.0	29.0	87.0	8.0	48.0	75.0	90.0	227.0
	20	0.0	22.0	30.0	36.0	106.0	20.0	71.0	106.0	141.0	357.0

Note: *Average
Note: Gravel number for all specimens is 'Sand'—A.

TABLE V

Samples of Stabilized Bases Placed in 1934
Analyzed 1935-36

County	Rd. No.	No. Tst.	Specific Grav.	% Moist.		Average Sieve Analysis of Stabilized Base Course												Liquid Limit	Plastic Limit	Plastic Indx
				In Base	1st Ft. of Soil	(Percentage Passing Sieve)														
						¾"	1½"	#4	#8	10	40	50	100	200	270	.005 M	.001 M			
Humboldt-Kossuth	60	19	2.144	6.7	......	96.6	92.8	77.6	65.4	62.3	24.9	21.5	15.9	13.4	12.47	4.73	1.6	26.43	17.47	8.96
Marion	181	16	2.55	4.1	......	92.9	88.1	68.7	57.2	53.8	17.4	15.5	12.1	11.4	10.9	3.68	1.4	22.54	14.00	8.54
Marion	156	9	2.36	2.3	......	93.8	91.3	69.4	53.8	50.4	25.5	19.2	13.0	8.7	8.4	2.63	1.3	19.75	12.75	7.00
Fayette	172	13	2.35	4.9	12.7	89.5	83.0	66.0	57.8	55.6	25.5	21.5	15.9	14.3	13.6	3.35	1.3	18.40	12.85	5.55
Grundy	185	4	2.35	5.7	19.3	95.8	90.6	73.2	62.7	60.0	28.7	24.5	18.7	16.5	15.7	4.5	1.6	24.4	15.7	8.70
Grundy	214	11	2.34	5.7	19.1	95.6	92.6	77.3	64.5	60.4	28.8	25.0	19.9	18.2	17.4	5.6	2.0	22.95	15.45	7.50
Montgomery	48	12	2.26	4.2	16.6	97.1	88.4	70.6	52.9	51.0	39.2	37.0	33.6	31.3	30.3	7.0	2.1	25.80	17.75	8.05
Cass	48	7	2.19	3.82	18.4	97.1	91.5	67.2	55.4	54.2	45.5	39.7	28.9	25.5	24.7	9.3	3.6	20.80	14.85	5.95
Harrison-Shelby Pott.	191	16	2.32	5.06	......	96.9	93.7	78.2	65.3	63.2	40.0	34.6	29.1	27.8	27.1	7.0	2.6	25.40	16.75	8.65
Shelby	37	6	2.32	3.32	......	94.0	90.0	78.1	68.2	65.9	40.2	33.0	26.5	24.5	23.8	6.9	2.7	22.41	14.2	8.21

TABLE VI

Average Moisture Tests of Base and Subgrade
1937

County	Rd. No.	No. Tst.	Mois. Tests of Base 1936	Mois. Tests of Base 1937	Est. % of Orig. Mois.	Moisture in Subgrade Soil Below Base Depth									Average % Mois. in 1st ft. of Sub Gr.		Ratio of Mois. in Sub Soil to Moisture in Mat. %
						0-1″	1-2″	2-3″	3-4″	4-5″	5-6″	6-8″	8-10″	10-12″	1937 Tests	1936 Tests	
Hancock Koss.	60	9	6.36	7.3	91	16.65	17.75	19.95	20.60	18.85	19.52	20.85	22.50	23.10	20.5		281
Marion	181	9	3.32	3.70	46												
Marion	156	5	2.44	2.74	34												
Grundy	214	6	5.79	5.84	73	14.9	15.4	18.4	21.4	19.5	20.7	28.9	30.8	19.1	24.3	21.9	416
Grundy	185	2	6.15	6.3	79	14.9	16.9	19.2	20.0	20.4	20.5	21.3	21.7	31.3	21.9	18.1	348
Fayette	172	8	4.10	5.2	65	12.7	14.2	15.1	16.0	16.0	15.8	18.5	20.2	19.4	15.9	11.9	306
Montgomery	48	10	4.29	4.41	55	16.3	17.5	18.8	19.6	19.9	20.3	21.2	22.2	22.6	20.4	16.9	462
Cass	48	7	3.83	4.65	58	16.8	18.7	20.1	20.0	20.6	21.5	20.2	21.0	19.5	18.4	20.0	395
Harrison-Shelby-Pott.	191	16	5.05	5.44	68	18.4	19.3	20.6	20.1	20.3	20.8	20.6	20.5	20.4	20.4		375
Shelby	37	6	3.32	5.28	66	16.7	17.6	18.2	18.0	17.3	17.3	19.3	18.0	19.3	18.4		336

1934. Samples of the base material were taken and density moisture content determined. The results of examination of these samples are shown in Table V.

These tests all showed a remarkably low moisture content particularly when considering the moisture present in the first foot of subgrade beneath. To verify this condition these same roadbeds were sampled again in 1937 with results shown in Table VI. In this you will note a remarkable correlation between percentages of moisture in the base for the two years 1936 and 1937. This time we took separate samples of subgrade soils for each inch for the first six inches and each two inch intervals thereafter to a depth of one foot. The average moisture content found in the first foot below the base varied from approximately 16 to 24% and 281 to 416% of the moisture in the base.

Unfortunately there are no records of the percentage of moisture in the bases at the time they were laid, or at the time the bituminous surface was placed. This data will be obtained on some of the bases being built this year.

From other work we would estimate that about 8% of moisture would be required to secure maximum density when placing these stabilized mixtures. By reference to Table VI we will note that the moisture content found in these bases was 34 to 90% of such an estimated basic or optimum moisture content.

The next question which presented itself was how is this moisture content affected by priming the surface of stabilized mixtures. To answer this question we prepared a large number of discs of soil aggregate mixtures on which we determine the moisture lost.

These specimens were made of uniform composition, molded at optimum moisture content inside brass rings 2″ high and 5″ in inside diameter. The bottom surface of the specimen as moulded was used for treatment. Since these specimens shrink as they loose moisture, it was necessary to cut grooves inside the brass retaining ring to engage the soil. Also a triangular filler ring was placed in the bottom of the mold to create by its removal a space for sealing the joint between the specimen and the ring. The specimens were allowed to age in the air of the laboratory or were ''subjected to capillarity'' by placing them on a moist layer of standard Ottawa sand.

To insure an ample supply of water the sand was kept saturated and about ¼ inch of water over the top. Specimens were weighed each day and as moisture evaporated additional water was added to maintain an approximately uniform level.

The first series of specimens was made to determine the effect of density and moisture content on the penetration of primers. The primers used were tars, TC-1, TC-2; Oils SC-1, SC-2; Cutbacks MC-1 and MC-2. Specimens were subject to capillary evaporation for one week before being primed. When the first group was primed the moisture content ranged from 2.70 to 5.15% or about 40 to 50% of the optimum moisture content. All specimens were primed with .4 gallon of the bitumen and after one week exposure to the air of the laboratory, the specimens were broken in half and the depth of penetration measured. This determination was necessarily only approximate for there was considerable variation in the depth of penetration and only one section was considered for each specimen. Also the bitumen was apparently not uniformly absorbed over the surface of the specimen for on considerable portions of some specimens much of the bitumen remained on the surface. However, the approximate rating of the specimens in the average penetration for various primers is shown in Table VII.

TABLE VII

Average Depth of Penetration of Various Primers

Rate of Application 0.4 Gal. Per Sq. Yd.

Primer	Depth of Penetration (inches)	
	Specimens with Normal Moisture	Specimens air dried to constant weight
TC-2	.435	.330
TC-1	.569	
SC-2	.419	.342
SC-1	.516	
MC-1	.577	
MC-2	.332	.358

In a second group the specimens were dried to a constant weight, then primed at the rate of .4 gal. per square yard. After one week they were broken open and the depth of penetration estimated. Only TC-2, SC-2 and MC-2 were used in this group. It will be noted that the depth of penetration on samples thoroughly dried was considerably less for both TC-2 and SC-2 than on material with normal moisture content. For MC-2 there was little difference.

In a third group of specimens the density of the soil aggregate mixture was varied by control of the tamping in molding the specimens. Some of these specimens were primed with normal moisture content and some in approximately dry condition, with results indicated in Table VIII. Four tenths gallon primer was applied per square yard.

TABLE VIII

Effect of Density on Penetration of Primers

Primer	Moisture Content		Density (% Solids)	Penetration (Inches)
TC2	(Dry)	0.26%	72.1	.29
	”	0.66%	74.3	.29
	”	0.48%	76.3	.25
	”	0.56%	77.1	.13
SC2	(Dry)	1.57%	70.2	.36
	”	0.68%	73.9	.50
	”	0.56%	76.3	.27
	”	0.55%	77.0	.30
MC2	(Dry)	0.68%	69.4	.27
	”	0.17%	72.1	.26
	”	0.40%	75.6	.12
	”	0.40%	76.9	.15
TC2	(Normal	3.59%	71.2	.48
	Moisture)	3.40%	74.0	.49
	”	4.50%	76.6	.42
	”	4.20%	77.7	.35
SC2	(Normal	4.62%	71.1	.47
	Moisture)	4.20%	73.8	.46
	”	4.90%	76.2	.37
	”	3.80%	77.3	.36
MC2	(Normal	4.49%	69.0	.43
	Moisture)	4.44%	73.6	.45
	”	4.33%	75.8	.28
	”	4.60%	76.7	.31

From this it will be noted that for both dry and moist specimens as the density increased the depth of penetration decreased.

To determine how effectively primers prevent the loss of moisture, a series of these specimens was placed on saturated sand and the moisture lost through the primed surface measured. The samples were compacted in the 5″ brass rings the same as the previous groups. The triangular space at the edge of the specimen was sealed with asphalt and then the surface was primed. On this primed surface was placed another brass ring 4″ in diameter, 3/8″ high and the surface outside this ring again sealed with solid asphalt. The details of this installation are shown in Figure 3. The sand on which the specimen rested was kept saturated, with the water level maintained about a quarter of an inch above the sand. When water was lost by evaporation the supply was replenished through a small hole in the lid. The only opening to this can, other than the primed surface was a small vent opposite the filling hole. The loss of moisture was determined each day. The average loss per week for various weekly periods is shown in Table IX. In this series the primers used were Tars, TC-1 and TC-2, Cutbacks MC-1, MC-2, RC-0 and RC-1 and Oils SC-1 and SC-2. These were applied at various rates from 0.1 to 0.4 gallons per square yard. In some cases both the specimens and the bitumens were at room temperature when applied. For other specimens the bitumen was heated while the specimen was at room temperature and for still others both the specimen and the bitumen were heated.

In general for applications less than 0.3 gal. per square yard the temperature of the specimen or the road surface was more important than the temperature of the oil. For .3 to .4 gal. per square yard the temperature of the specimen had very little effect. Heating the bitumen at application generally resulted in slightly reducing the moisture loss.

The application of all primers even at as low a rate as 0.1 gal. per square yard greatly reduced the moisture loss. With each primer the effectiveness in sealing increased as the rate of application increased from 0.1 to 0.4 gal. per square yard. The mean weekly loss for various primers is shown in Table X in grams per square centimeters; in inches of water over the surface and in percentage of the loss from untreated specimens The loss in inches of water per week is shown in Figure 4.

It will be noted that with untreated surfaces the loss was nearly equal to 3.5 inches of rain per week. The highest loss from a primed surface was from that primed with Cutback MC-2, applied at 0.1 gal. per square yard. This amounted to approximately 8.6% of the loss from untreated specimens or the equivalent of 0.3 inch of rain per week.

The most effective sealing was secured with 0.4 gal. of MC-1 per square yard, which showed a loss of only 0.243 percent of the loss the untreated surface or 0.008 inch of rain per week. The Tars show the least loss for application of 0.1 gal. per square yard. For application of 0.2 gal. the RC-1 oil shows the least loss.

Insofar as moisture loss is concerned as indicated by these results, the loss from surfaces primed with 0.2 gal. of RC-1 is

TABLE IX

Moisture Loss of Stabilized Surface Treated With Various Primers

Primer	Rate of Application Gal. Per Sq. Yd.	Temperature Surface	Temperature Primer	Number of Specimens	Moisture Loss Per Week Gms. per Sq. Cm. Week 1	2	3	8	13	18	23
Tar TC-1	0.1	Room	Room	3	.53	.51	.45	.41	.43	.43	.37
	0.1	Room	Hot	1	.67	.67	.65	.63	.56	.56	.54
	0.1	100°F.	Hot	1	.50	.53	.46	.55	.59	.42	.....
	0.2	Room	Hot	1	.34	.33	.31	.39	.36	.37	.34
	0.2	100°F.	Hot	1	.26	.27	.27	.25	.23	.24	.....
	0.25	100°F.	Hot	3	.18	.19	.18	.17	.15	.....	.....
	0.4	Room	Hot	1	.02	.04	.03	.06	.06	.07	.....
	0.4	100°F.	Hot	1	.10	.08	.08	.08	.11	.09	.....
Tar TC-2	0.1	Room	Room	3	.47	.45	.43	.41	.47	.46	.46
	0.1	Room	Hot	1	.58	.56	.59	.60	.52	.49	.54
	0.1	100°F.	Hot	1	.50	.53	.52	.54	.57	.41	.....
	0.2	Room	Hot	1	.31	.29	.27	.35	.28	.24	.23
	0.2	100°F.	Hot	1	.19	.21	.15	.19	.22	.23	.38
	0.25	100°F.	Hot	3	.17	.18	.20	.14	.....	.....	.....
	0.3	100°F.	Hot	3	.11	.11	.11	.....	.....	.....	.....
	0.4	Room	Hot	1	.02	.01	.02	.01	.03	.03	.....
	0.4	100°F.	Hot	1	.04	.05	.05	.06	.16	.15	.....
Oil MC-1	0.1	Room	Room	3	.69	.69	.62	.55	.67	.63	.59
	0.1	Room	Hot	1	.63	.66	.60	.64	.58	.60	.61
	0.1	100°F.	Hot	1	.41	.45	.45	.51	.57	.45	.....

	0.2	Room	Hot	1	.38	.37	.35	.40	.39	.40	.42
	0.2	100°F.	Hot	1	.34	.43	.35	.60	.76	.39	.44
	0.4	Room	Hot	1	.01	.02	.02	.02	.04	.02	.....
	0.4	100°F.	Hot	1	.02	.04	.01	.02	.05	.03	.....
Oil MC-2	0.1	Room	Room	3	.82	.87	.80	.73	.68	.81	.64
	0.2	....	Hot	3	.16	.18	.20	.21	.....	.....	.....
	0.4	....	Hot	2	.08	.09	.08	.12	.15	.13	.....
Oil SC-1	0.1	Room	Room	2	.54	.52	.45	.39	.41	.49	.43
	0.1	Room	Heated	2	.42	.39	.41	.39	.40	.35	.....
	0.2	Room	Heated	2	.29	.28	.27	.31	.30	.29	.31
	0.4	Room	Heated	4	.12	.10	.10	.11	.12	.....	.....
Oil SC-2	0.1	Room	Room	3	.65	.54	.46	.41	.39	.38	.37
	0.1	Room	115°F.	2	.50	.50	.48	.50	.49	.42	.....
	0.2	Room	115°F.	2	.30	.35	.27	.37	.34	.30	.30
	0.4	Room	115°F.	5	.09	.09	.08	.10	.10	.....	.....
Oil RC-0	0.1	Room	Room	3	.82	.82	.70	.75	.82	.77	.75
	0.1	Room	Heated	2	.64	.70	.64	.70	.69	.63	.....
	0.2	100°F.	Heated	2	.28	.36	.38	.34	.34	.37	.36
	0.4	100°F.	Heated	2	.07	.07	.07	.11	.11	.07	.....
Oil RC-1	0.1	Room	Room	3	.28	.28	.23	.28	.27	.30	.33
	0.2		Heated	2	.02	.02	.03	.06	.06	.12	.07
	0.4		Heated	2	.02	.02	.02	.02	.04	.04	.....
Untreated Surface				9	10.48	9.91	8.52	9.87	8.70	7.05	6.87

TABLE X

Comparison of Moisture Losses From Primed Surfaces

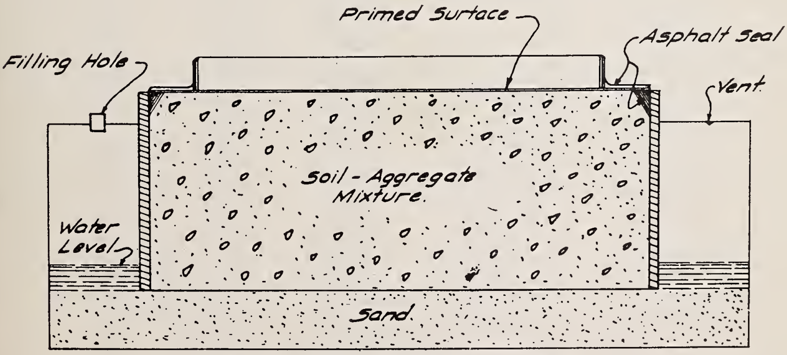
Primer	Rate of Application Gal. per Sq. Yd.	Mean Loss of Moisture Per Week		
		Gm. Per Sq. Cm.	Inches of Water	Percentage of Loss from Untreated Surface
Tar				
TC-1	0.1	0.447	0.176	5.085
	0.2	0.305	0.120	3.470
	0.25	0.174	0.068	1.980
	0.4	0.0585	0.023	0.666
TC-2	0.1	0.45	0.177	5.119
	0.2	0.253	0.100	2.878
	0.25	0.1725	0.068	1.962
	0.3	0.110	0.043	1.251
	0.4	0.045	0.018	0.512
Cutback				
MC-1	0.1	0.634	0.250	7.213
	0.2	0.431	0.170	4.903
	0.4	0.0214	0.0084	0.243
MC-2	0.1	0.754	0.297	8.578
	0.2	0.1875	0.074	2.133
	0.4	0.1083	0.043	1.232
Oil				
SC-1	0.1	0.462	0.182	5.256
	0.2	0.193	0.076	2.196
	0.4	0.110	0.043	1.251
SC-2	0.1	0.457	0.180	5.199
	0.2	0.319	0.126	3.629
	0.4	0.0920	0.036	1.047
Cutback				
RC-0	0.1	0.776	0.306	8.828
	0.2	0.347	0.137	3.948
	0.4	0.0833	0.033	0.948
RC-1	0.1	0.282	0.111	3.208
	0.2	0.0543	0.021	0.618
	0.4	0.0266	0.010	0.303
Untreated Surfaces		8.790	3.460	100.000

approximately equal to that from surfaces primed with 0.4 gal. of tar TC-1 or TC-2.

These test results are only a slight indication of some of the differences which may be obtained between various materials. No doubt the results would be more conclusive if the number of specimens were multiplied. The work will be continued and amplified as questions present themselves and time permits. Studies of moisture loss have been limited to evaporation from a primed surface. We tried also to determine the permeability of such surfaces, but leakage around the specimen produced erratic results. We expect to try merely inverting our present specimen on the moist sand and exposing the untreated stabilized base to evaporation. Water will be supplied only through the primed surface and will be drawn up to the surface by capillarity.

From results at hand it seems reasonable to state that we may expect to develop some beam strength in stabilized soil-aggregate mixtures **if we can reduce the moisture content below 50% of that required for Optimum moisture** at time of placing the mixture.

There is possibility that priming the subgrade may contribute materially to the maintenance of this low moisture content. From the standpoint of sealing the surface of soil-aggregate mixtures 0.4 gal. per square yard of MC-1 was the most effective primer tried.



Primed Soil Aggregate Mixture
Exposed to Capillary Evaporation.

Figure 3.

Figure 4 (Sheet 1)

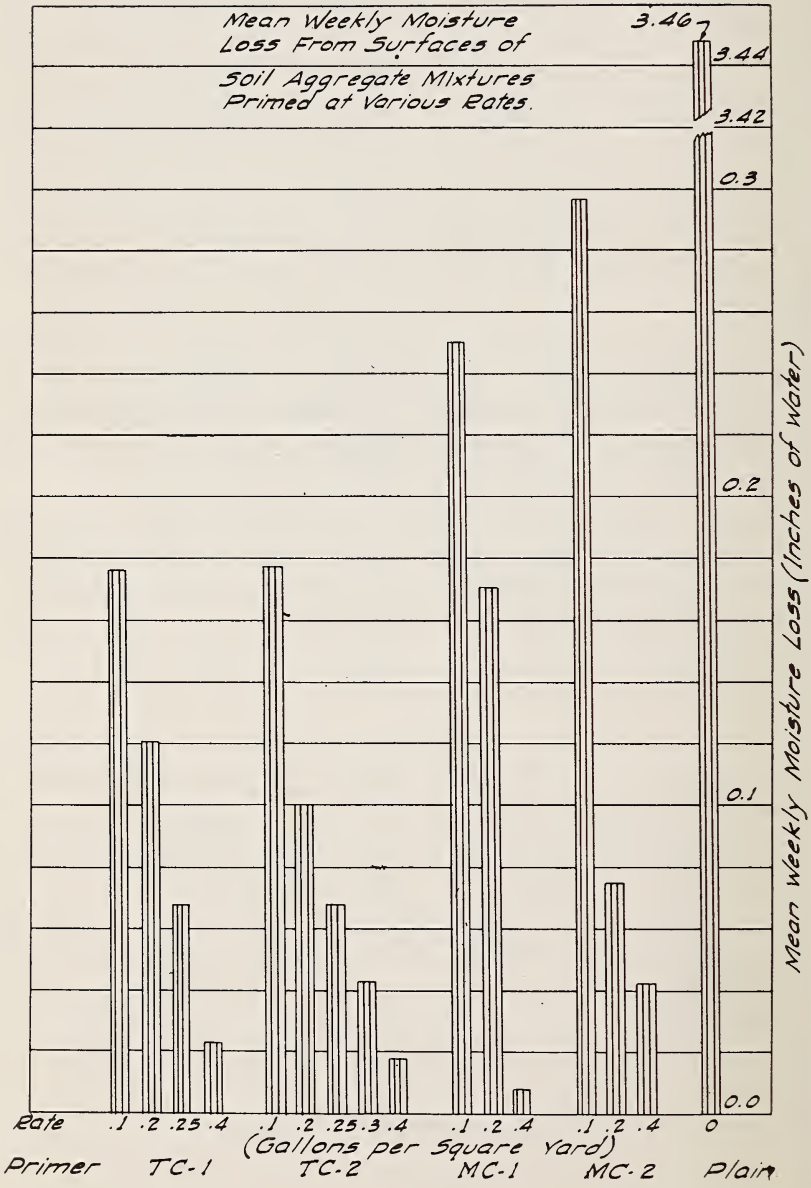
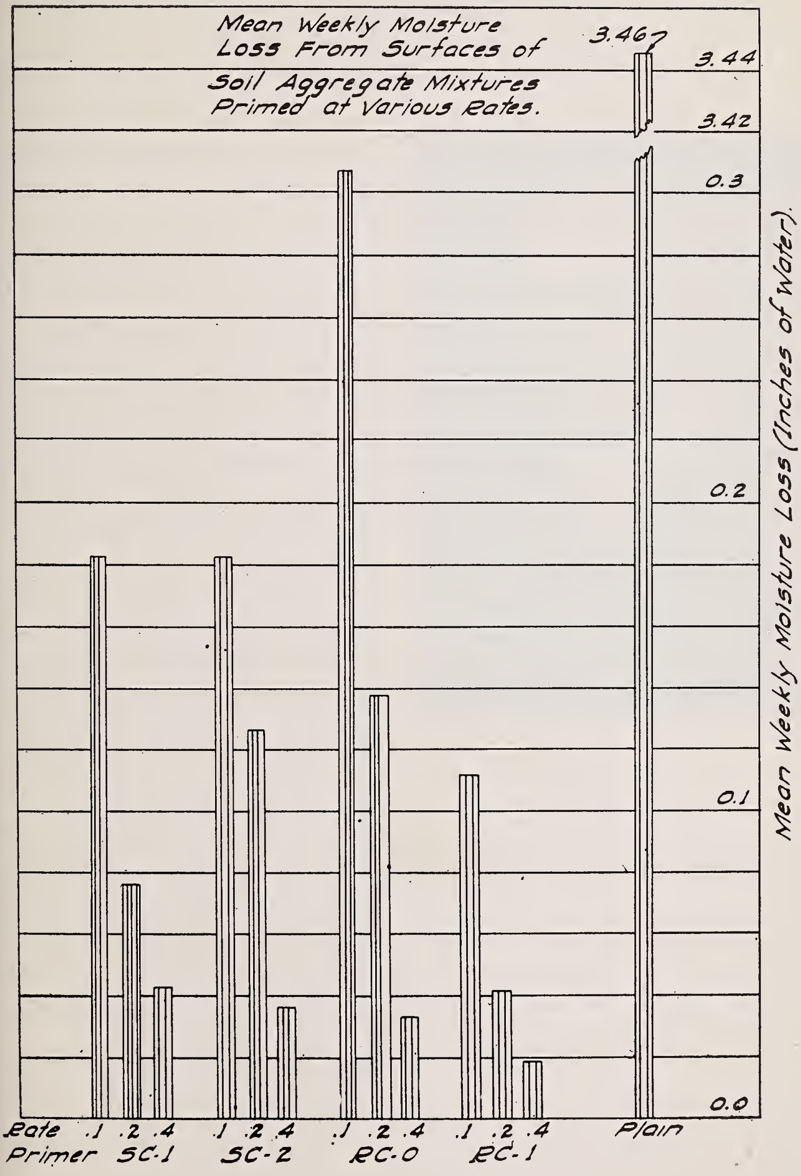


Figure 4 (Sheet 2)



Emulsified Asphalt in Soil Stabilization

By

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Soil stabilization with emulsified asphalt is, like road oil mixes, a child of necessity. Road oil mixes came into general use because there were many thousands of miles of crushed stone and gravel surfacing, particularly in the Western states, which was rapidly wasting away, and no funds were available for the construction of standard types of pavement.

Soil stabilization had its inception in a large airport in the east which was being used as a commercial airport, but on which no funds for paving were available. With little information upon which to base the design, the natural clay soil of this airport was treated with emulsified asphalt, hoping that it would be at least a temporary expedient. The remarkable success of the treated surfaces led to extensive research work and to subsequent construction on airports and highways, and as a result the underlying principles are now well understood. In the seven years since this first airport job which was so successful that it was used without further treatment for several years, many jobs have been constructed in almost every state of the Union, with phenomenal success. The utilization of local materials has long been the dream of every road builder. The successful use of unstable clay soils as road base, as has been demonstrated to be feasible in many cases, is intriguing to the highway engineer.

A number of papers have been written during recent years upon this subject, and most engineers are now familiar with the process. Therefore, this paper will consist of a Progress Report, commenting on recent developments, together with a brief description of the method, for the benefit of those who have not had actual experience with this type of construction.

Soil stabilization with emulsified asphalt as a stabilizer consists of the treatment of normally unstable soils and of pit run or clayey gravels with sufficient asphalt in an emulsified form to render such soils stable and resistant to displacement during the wet seasons of the year. By preventing absorption of appreciable amounts of moisture these stabilized surfaces have been found highly resistant to frost action, even in climates as severe as those encountered in Vermont and Massachusetts.

In this process of stabilization the soil is wetted with water to break down lumps and to separate the soil particles so that the minute particles of asphalt in the emulsion can be dispersed uniformly throughout the mass. A predetermined amount of dilute emulsified asphalt is added and mixed in uniformly. The mixture is then laid in place and allowed to dry while it is being compacted with suitable rollers or under traffic. The drying operation causes the minute asphalt particles to be drawn over the surface of the clay particles and to form an adsorbed film which is highly water resistant. If the proper amount of emulsified asphalt has been used, and the mixing uniformly done, the soil, when once dried and compacted, would not again absorb by capillarity sufficient water to cause loss of its supporting power.

In this soil stabilization work the emulsified asphalt is not used as a binding agent, although it does somewhat increase the binding strength of the soil. Only sufficient stabilizer is used to waterproof the surface of the soil particles without interfering with the cohesive strength normally set up by the clay in the soil. The process, therefore, requires much less emulsified asphalt than would be used as binder for a fine aggregate mix, thereby not only saving cost in asphalt, but making use of natural materials costing little or nothing.

Various grades of asphalt material have been used and the absorption is reduced about equally regardless of the hardness of the bituminous material, but it has been found that the stability of the dried mixture increases with the hardness of the asphalt. A stabilized mix is 50% more resistant to displacement where 50 to 100 penetration asphalt is used as compared with 250 to 300 penetration asphalt.

This process, like all other economical methods of construction, requires care in handling and scientific control to insure that best results will be obtained. Each of the construction steps must be carefully and completely carried out, as each is of extreme importance.

Tests must be made on the soils in advance of the construction operation, to determine the amount of emulsified asphalt which is necessary for that particular material. Occasionally soils are found which do not react to the treatment satisfactory. Some will be found which require only small quantities of emulsion, while others require an amount which might make the process uneconomical unless coarse aggregates are added to lower the natural fines content. In other words, each soil has its own characteristics, and in order that the work can be constructed economically and properly, it is necessary to study each material to be treated before the work is done.

Several rather simple tests have been worked out which simplify the preliminary study of soils contemplated for use on this type of stabilization. One of these is the usual hydrometer method of analysis which determines the particle size distribution of the soil grains. Another is an electrical conductivity test which determines the presence of soluble salts in the soil which would hinder proper stabilization. The third and fourth tests are the absorption and stability tests which determine the efficiency of stabilization and which have been described in detail in several previous papers.

By the use of these tests it is possible to determine, first, whether a soil will react economically to stabilization with emulsified asphalt, and second, the quantity of emulsified asphalt which is necessary for optimum stabilization. A full description of these tests may be found in the 1935 Proceedings of the National Highway Research Board.

Although this process is called ''Soil'' Stabilization it has been found effective and economical where other types of aggregates have been used such as: crusher waste, disintegrated granite, clay gravel, etc. A soil or aggregate, or a soil-aggregate blend, is selected which, when wetted with water and allowed to dry, will develop sufficient binding strength and internal resistance to movement to support the load it is being designed to carry. Some soils have the desired binding strength and load carrying ability when dry, but are found to require an excessive amount of emulsified asphalt for economical stabilization, and are therefore blended with coarser materials to reduce the quantity of stabilizer required. It is necessary for the engineer to study local aggregates and soil supplies, and to develop the most suitable and economical blends.

Although the use of emulsified asphalt as a stabilizer has been developed and proven to a point where this type of construction is becoming very common in road and airport construction, improvements of methods are being continuously developed by the engineers responsible for the work. Lower costs and increased efficiency are the results.

The general trend in soil stabilization is toward the use of traveling mixing machines and stationary mixing plants, although some work is still being done with blades and harrows. This is the same trend which was followed in the progress of oil and cutback mixes. The uniformity of results obtained with the better mixing equipment makes it definitely worthwhile to obtain the use of such equipment wherever possible.

Another change which is gradually taking place is that with improved mixing equipment less water is being found necessary in the mixing of the emulsified asphalt and soil. When the process was first developed it was thought necessary to wet the soil to near its liquid limit during the process of mixing, and this excess of water caused no little difficulty during shaping and drying out of the stabilized material. It now develops that it is not necessary to make a mud mix in order to obtain satisfactory results. While better mixing equipment has been largely responsible for this progress, mixing with blades and harrows, when properly done, will usually give successful results without using an excess of water.

Drying has been found to be facilitated through the use of the better methods of laying the mixture. A very satisfactory method for improving the rate and extent of drying is to first lay out the bottom inch or so of mixed material on the subgrade, and allow it to dry with rolling, for usually about 24 hours before placing the remainder of the mixture. This dry bottom layer prevents the infiltration of moisture from the subgrade. **Stabilization is never complete until thorough drying has taken place.** This must never be forgotten. It has been found that if the mixture is placed on the subgrade to full depth, the subgrade will frequently furnish enough moisture to prevent thorough drying out of the bottom portion of the mix. When placed to the full depth in one layer the rapid drying of the surface renders the surface highly resistant to the escape of moisture from the still saturated lower portion.

Another improvement in the process is the use of slightly more emulsified asphalt in the bottom inch of the material than is used in the body of the mix. This is desirable, particularly where the mixing is done in place, as the excess of stabilizer tends to take care of any untreated material which might be drawn into the mixture during the mixing and laying out operations. This increased asphalt content also increases resistance to capillary movement of water at the place where this is most needed, that is, where it contacts the untreated soil of the subgrade.

The trend in rolling for this type of work is toward the use of a new type of roller made up of rows of pneumatic tires, and toward the use of sheeps foot tamping rollers. Both of these rollers develop very satisfactory density in wet mixtures, and more uniformly compact the work. The sheeps foot tamping roller also has the advantage of compacting from the bottom upward, causing more rapid dehydration of the layer.

Unsurfaced stabilized base has been subjected to traffic in a few instances, and the results have been surprisingly satisfactory, but this is not generally believed to be economical because the bituminous content in the stabilized base is very low, and unless the base mixture is very granular, losses due to abrasion would be expected to be high.

It has been found, particularly in large areas such as airport runways where drainage is rather poor, and also in regions of heavy precipitation, that a dense type of surfacing is necessary. While a stabilized base will not absorb water by capillarity from the subgrade, and is highly resistant to the absorption of water impounded on its surface, long continued soaking may result in some surface softening. When the surfacing consists of an open type, such as an Armorcoat or retread, water is impounded in the surfacing, and due to the fact that it will not be absorbed into the base, remains impounded, and sometimes results in softening and disintegration of the surface.

Very successful stabilized base work has been built in Louisiana and other Southern States in regions where the rainfall is almost continuous the year round, which consists of penetration Armorcoats one inch in thickness, covered with about one-half inch of densely graded cold plant mix made with emulsified asphalt of a softer grade than that used in the base. This has resulted in an absolutely impervious surface which has gone through several seasons without damage. Cold densely graded mixes made with emulsified asphalt and other bituminous binders laid 1½ to two inches in thickness have also been very successful.

When the soil contains an appreciable amount of granular substance capable of taking abrasion, satisfactory results may be obtained by enrichening the top one-inch of the stabilized base by adding approximately one half gallon of stabilizer, and after drying and compacting, treating with a seal coat of emulsified asphalt or other bituminous material which is soft enough to impregnate the surface of the roadway.

The question is frequently asked, ''What thickness is required for a stabilized base?'' There is, of course, no fixed answer to this question. The minimum thickness should be 4 inches except where the subgrade is absolutely unaffected by moisture. Under very heavy traffic or bad subsoil conditions, thicknesses of 10 inches or even more have been used, but it is believed that for normal low cost road construction the thickness may vary from 4 to 6 inches.

In general, the use of emulsified asphalt in stabilization of soils and aggregates has increased tremendously in the last two or three years. Last year emulsion was used in stabilization of over twenty-two airports, as well as many miles of highway and city streets. This year, the amount of this work done has far surpassed that of the previous year.

OTHER USES

Soil stabilization is not only being used in highway and similar construction, but in the manufacture of sun-dried bricks stabilizer is added to the soil to prevent moisture absorption and disintegration from the weather. This industry alone is growing rapidly. The use of stabilized soil for core walls in earth dams seems feasible and economical and research studies are now under way. The treatment of earth slopes to prevent erosion and the use of revetments and slope protection consisting of the placing of bags filled with wet stabilized soil has already been proven effective and economical. This is an effective substitute for rip-rapping because by the time the bags have rotted away the soil has dried and become waterproof.

The Present State of the Adhesion Problem in Bituminous Road Construction

By

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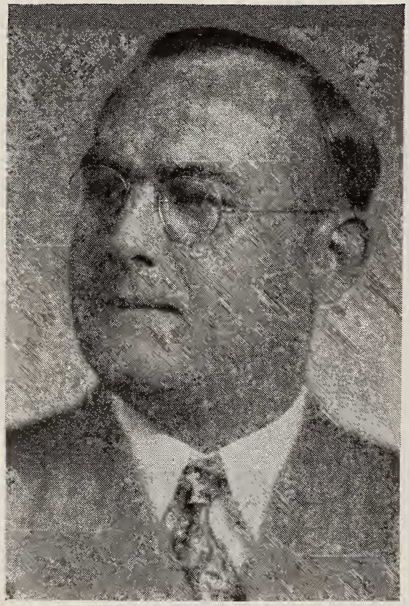
INTRODUCTION



One of the most important problems confronting the bituminous industry and the engineer engaged in the construction of bituminous roads concerns the understanding of the factors which govern the adhesion of bitumen to mineral aggregate and fillers, the establishment of a dependable testing method, and the development of primers and addition substances to promote better adhesiveness where needed. The importance of this threefold problem is generally recognized and as a result there is a voluminous literature dealing with theoretical and experimental investigations, and a number of patents for the improvement of the adhesiveness of bitumen. Considering the emphasis placed at the present time on low-cost roads, and the extensive use of bitumen in this type of construction it appeared opportune to take stock of our accumulated knowledge on the adhesion problem. The study of the literature convinced us furthermore, that such a survey was especially desirable at this time since the first general attack on the adhesion problem appears to have come to a successful ending, permitting at least the logical, although qualitative, exposition of the factors involved. Therefore, an attempt in this direction has been made in the following.

GENERAL FUNDAMENTALS

If adhesion is defined as the resistance to separation of two adjoining materials, then, obviously, this adhesion may be due to non-specific, i.e. mechanical factors or to specific surface-physical or chemical phenomena. Mechanical adhesion may be compared to a mortised joint and can be caused by plugs of bitumen which have solidified in the pores of the aggregate. The introduction of bitumen into these pores can be facilitated by heating the bitumen and the aggregate, by cutting the bitumen with a lighter liquid, which is either volatilized or sorbed into the micropores of the aggregate, or by emulsification of the bitumen in water and subsequent coagulation of the bitumen globules in the pore space while the water may either be left, or sorbed into the micropores of the aggregate, or evaporated.

Beside and irrespective of this mechanical adhesion there exist specific adhesion phenomena which are functionally connected with the physical and chemical character of the mineral surface and of the adhesive. These phenomena may range from purely physical adsorption (defined as a function solely of the amount of mineral surface present and the concentration and molecular weight of the absorbate), through oriented adsorption, (brought about by interaction of specific surface elements of the mineral surface with certain active groups of the adsorbate) to the formation of insoluble compounds by chemical interaction of the mineral surface with the adhesive. A survey of the substances which are important either as components or as natural enemies of mineral-bitumen systems makes it evident that purely physical adsorption can play only a very negligible role, if any, in the adhesion problem and that primary attention should be paid to orientation and reaction phenomena. Since the latter (polar adsorption and compound formation) take place with considerable more energy than physical adsorption their importance is all the more obvious. Therefore, in any practical problem one should look for the possibilities and types of polar adhesion and compound formation on the basis of the chemical compositions of the binder and of the mineral surface.

STUDIES ON ADHESION PHENOMENA

In line with the foregoing, the adsorption of the adhesive on the surface and the filling of the interstices followed by a hardening of the adhesive constitutes a cementing process. In the theoretical treatment of this process by different workers interested in this field of research emphasis was laid either on the physical or the chemical aspect of the problem. From a kinetical or purely physical standpoint, the energy of adsorption should be directly proportional to the molecular weight of the adsorbed molecules. Since the consistency of bituminous materials increases with increasing molecular weight of its components, an increase in adsorption, and therefore, in adhesiveness should be expected with increasing consistency. In accordance with this Lewis and Hillman (1) found that bonding strength is roughly proportional to the consistency of the original bitumen. Klinckmann (2) also states that the adhesiveness is, in general, indicated by the viscosity of the binder; furthermore, in Kirschbraun's (3) opinion the binding properties should be gauged by considering the relation between ductility and hardness. The foregoing considerations explain why consistency tests have obtained an important place in the specifications and standards of the various road building agencies.

It has been mentioned before that purely physical adsorption, as defined above, probably plays only a very small role in the adhesion problem. But this fact does not lessen the practical value of the consistency-adhesion relation since it so happens that the larger molecules in the bitumen are also the more active ones from a physio-chemical point of view because of multiple linkage and active groups. There exists, therefore, a factual connection between the findings of the exponents of the physical aspects of the binder problem and of those workers who are more interested in the underlying physico-chemical and chemical phenomena. Of course, the results of the latter are of more fundamental importance, since they permit a deeper understanding of the mechanism of adsorption and adhesion and thereby indicate the tools by which one might be able to influence the linkage between minerals and binders.

The theoretical and experimental foundations for the understanding of surface phenomena were laid by such men as Gibbs (4), Hardy (5), Langmuir (6), Haber (7), and Harkins (8), from a thermodynamical as well as kinetic point of view. Qualitatively, Harkins has given the best formulation in stating that two systems tend to react with each other in a way to make the transition at the interface less abrupt. This interpretation clearly indicates the importance of the chemical composition of the mineral surface and of the binder material, and also that of the influence of time in the case that the binder consists of a mixture of particles with different activities, since a certain amount of time might have to be allowed to the more active particles for their migration to the interface. The energy of adsorption can be approximately calculated from atomic, ionic and molecular data, it can be evaluated thermodynamically from adsorption isotherms, or it can be determined experimentally in the form of heat of wetting. Such thermic measurements were made by Gurvich (9). By comparing the heat of wetting and adsorption of floridin, clay and charcoal with various organic compounds and water he found that the oxygen-compounds exhibit a greater heat of wetting with, and are also better adsorbed by, adsorbents containing oxygen. These compounds are called ''oxophil'' while hydrocarbons which are better adsorbed by charcoal are called carbo-phil. With increase of molecular weight of a series the effect of the oxygen decreased to a minimum at about C_5 while after that the adsorption improved again because of the increase in molecular weight. The same author (10) had samples of paraffin and resin containing petroleum shaken for an hour with 10% of Florida earth and with infusorial earth at room temperature and then filtered through glass wool at 50°C. The analysis of the filtrate and of the filter medium indicated that resins and asphalts are more strongly adsorbed than paraffin, and that in the paraffin group adsorption increases with the molecular weight. Bibra (11) reviewed the theory of adsorption as applied to the use of clays in refining petroleum distillates coming to the same conclusions as those stated. Nutting (12) in a geological study obtained data of interest in this connection. According to him water adsorbed by silica and silicates may be displaced by the stronger (brown or black) hydro-carbons, but not by the weaker lighter ones. Petroleum may enter and fill sands previously wet by water or aqueous solutions provided the petroleum compounds contain basic constituents stronger than the hydroxyl group. Thereby the character of the silicate is changed from hydrophilic to hydrophobic. The most efficient flotation oils for sulfide ores are those composed of hydrocarbon derivatives which contain groups just a little weaker than the hydroxyl ion. Another contribution from the geological side bearing on our problem is that by Luyken and Bierbrauer (13). According to these authors it has been found possible to recover apatite by flotation with sodium palmitate as a reagent. This is believed to be caused by the adsorption of the fatty acid radical on the calcium of the mineral. The hydrocarbon chain by virtue of its incompatibility with the water attached itself to the air bubble which carries up the solid particle. Cassiterite, adsorbs palmitate only after a preliminary treatment with calcium hydroxide, after which very good recovery is obtained. These are examples of "chemical" adsorption the importance of which in bituminous road construction shall be discussed later. Russel (14) studying the adsorption of liquids by clays comes to the conclusion that nonpolar liquids are adsorbed weakly or not at all, while the adsorption of polar liquids appears to be due to the orientation of the dipole molecules in the electrostatic fields around the clay. Winterkorn (15) had arrived at the same conclusions as a result of a study of the swelling of clays in liquids of different character. McBain (16) in discussing the effect of orientation in adsorption mentions the experiment of Deveaux (17) on the different wetting characteristics of the upper and lower surface of a fatty acid drop which has been permitted to solidify on water. The importance of surface orientation in adsorption has also been emphasized by a number of other investigators. Ever since Freundlich's work (18) adsorption isotherms have been used to determine the adsorption power and adsorbabilities of different substances. Wilhelmi (19) and Neumann and Wilhelmi (20) working with diluted solutions of various bituminous binders in benzene (1 gm. per liter) determined the adsorption isotherms on rock powders by a colorimetric method. It was found that Trinidad asphalt, free from mineral matter, was most strongly adsorbed, followed in turn by Mexican and Californian asphalts and by tar. Asphaltenes were more strongly adsorbed than the oils, hard asphalts, with high asphaltene content were better adsorbed than soft asphalts. The rocks used as fillers were classified in the following order in regard to their adsorption power. Trinidad filler, slate, basalt, prophyry, granite, limestone, Kaoline, and quartz. Similar work was done by Dow (21) and by Tolstopyatov (22). Of course, adsorption measurements are of importance only if the energy of adsorption can be derived from these, which again has to be compared to the energy of adsorption of water, which is the most important destructive agent in bituminous roads. If water is adsorbed with greater energy than the bitumen the material is hydrophilic, if it is adsorbed with lower energy the material is hydrophobic. If one keeps in mind that it is the energy of adsorption which determines whether a given surface attracts bitumen better than water and vice versa, it is easy to avoid the fallacy of attributing good adsorption and connected properties to liquids of low surface tension in a misinterpretation of the fact that many good wetting agents possess low surface tension. If we bring together, in a vacuum, two surfaces each of 1 $cm.^2$ representing the surface energies $\sigma 1$ and $\sigma 2$ respectively and call the interfacial tension σI, then the energy of adhesion will be $\sigma 1 + \sigma 2 - \sigma I$. In determining the wetting or spreading properties one can start out from a drop of liquid of negligible surface resting on a 1 $cm.^2$ plate. If $\sigma 1$ is the surface energy of the plate σI the interfacial energy of 1 cm^2. liquid solid interface and $\sigma 2$ the surface energy per cm^2. of the liquid then spreading-wetting of the liquid will occur only if $\sigma 1 - \sigma 2 - \sigma I > 0$. Thus it is seen that a non spreading liquid with high surface tension may be more strongly held on a given surface, than a spreading liquid with low surface tension. Again it deserves to be emphasized that the two surface tensions and the interfacial tension should be known before anything definite can be said about the adhesiveness of two materials from a surface-energy point of view. Unfortunately there does not yet exist a dependable method for the determination of the surface or interfacial tension of a solid material (23). Consequently, the value of data on surface tension in gauging the adhesiveness of bitumen is quite restricted, contrary to the opinion of Nellensteyn (24) and McBain (16). Of course, certain conclusions can be drawn from these data in regard to wettability as is stated accurately by Klinckmann (2). Wettability rather than adhesiveness is also indicated by the determination of angles of contact by Lee (25), Fricke and Meyring (26) and others. Freundlich (27) defined as adhesion tension (and as a measurement for adhesion) the difference between the surface tension of the solid and the interfacial tension solid-liquid.

$A_{12} = S_1 - S_{12} = S_2 \cos \theta$ in which
A_{12} is adhesion tension (adhesion)
S_1=surface tension of solid
S_2=surface tension of liquid
S_{12}=interfacial tension of solid-liquid
θ=angle of contast of the liquid on the solid

The fact that, according to this equation, the adhesion energy becomes equal to the surface tension energy of the liquid in the case of a zero angle of contact, should have started a critical examination of the theoretical foundations of the equation. Instead, a new constant was introduced by Bartell and his associates (28) to make the equation usable for liquids possessing zero angle of contact. Bartell and co-workers have developed a very interesting method for the measuring of adhesion tension but, according to Riedel and Weber (29) this method is unsuitable for the testing of road materials. It is too complicated and consumes too much time, while, for bituminous binders, the difficulties are increased in that the determinations have to be made at elevated temperatures. It appears that, as a result of the subtility of this method, no outside worker has been able to work with the Bartell apparatus. Concerning the determination and evaluation of surface and interfacial tensions, contact angles, and displacements of liquids by others, it should be stated categorically that the theory of these phenomena is based on the assumption that the molecules acting in the system are highly symmetrical in shape and in properties, and that each of the liquid phases is made up of one species of molecules. Deviations from the theoretical behavior are apparent with pure water, because of the polar molecules, e.g. because of dipole orientation the surface energy per cm^2. for water is less than ½ of its cohesion. With bituminous materials which represent mixtures of many components of different molecular properties, such great deviations from the behavior of ''ideal'' substances can be expected and obtained by positive and negative adsorption and by orientation at the surface and interface that it can almost be said that the surface of a bituminous phase changes its chemical properties with each new contacting phase. This is illustrated by the above mentioned experiment of Devaux.

The importance of a good adsorption of the bituminous binder on the surface of the aggregate or filler appears to be generally recognized. But obviously the adsorption has to be qualified since it is of equal importance in such diametrically opposite fields as cementation and lubrication. At this point it might be enlightening to cite the work of such authorities as DeBoer (30) and Hardy (5). According to DeBoer: ''Hydrocarbons may be bound to metal surfaces by Van der Waals forces, the molecules here lying flat on the surface. A second layer of molecules can be formed upon the first by the addition of other molecules in corresponding parallel position above the first, just as was the case when dealing with water surfaces. Liquid hydrocarbons spread themselves out on metal surfaces even better than upon water surfaces. Molecules of fatty acids, on the other hand, are absorbed on metal and on water surfaces with their dipoles directed towards the surface, thereby pushing away the molecules of the hydrocarbons. No new molecules of fatty acid can be adsorbed on a metal surface which is already occupied by a mono-molecular layer of fatty acid molecules, because the Van der Waals forces of the hydrocarbon end of the fatty acid molecules which act in a direction away from the surface are smaller than the mutual Van der Waals attractive forces of the fatty acid or hydrocarbon molecules. Thus the hydrocarbons and fatty acids do not spread out upon an already existing mono-molecular layer of fatty acid, but form lenses."

Hardy (5) has shown that a double bond decreases the lubricating action of a ring compound, but increases that of a chain compound. When a ring and chain are jointed, as in butyl xylene, the result is a better lubricant than either. Simple aliphatic esters possess much less lubricating ability than their related acids or alcohols. The ring esters, on the contrary, are better lubricants than their related acids.

With the hydroxy acids the conjunction produces a remarkable increase in the lubricating power of a chain compound, and destroys lubricating action in the case of ring compounds. In the ring compounds the replacement of hydrogen decreases the lubricating power in the case of N, O, or COOH, and increases it in the case of other groups in the order $C_2H_5 > CH_3 > OH$. The establishment of a cementing film may be connected with orientation, oxidation and polymerization. From this it appears that the constitutional properties of the molecules in the bitumen are of importance not only in the establishment of a well adsorbed surface film but also in further deciding its lubricating or cementing character. Of course, the role of these molecules is strongly influenced and directed by the chemical character of the adjoining surface. Beside influencing the orientation of dipoles in the bitumen, and determining the character and extent of eventual chemical combination, it may influence the establishment and the properties of a cementing film by a catalytic effect on condensation, polymerization and oxidation phenomena.

The influence of the character of the stone on adhesion of the bitumen has always been observed by and known to the experienced road constructor. In the literature this has been emphasized by Saal (31), Lee (25), Riedel and Weber (29), Winterkorn (32) and others, some of whose work has been mentioned above. Lee, in an excellent discussion of the factors involved in cementing with bitumen, points out the close connection between adhesion and the architecture of the molecules, but he does not overlook the great influence in actual service of the physical properties of the aggregate. The experimental work of Riedel and Weber has been quite valuable in demonstrating the chemical side of the adhesion problem, although at some phases a more critical evaluation of the data by the authors would seem to be desirable. The work of Winterkorn has shown that the waterproofing effect of bitumen on soil material is a function of the composition of the bitumen and also of the matrix composition and of the amount and kind of exchangeable ions of the soil-mineral particles. Iljin (33) has given an electrostatic formulation of Harkins' rule by using the electric moments of the adsorbent, adsorbate and solvent molecules.

TESTS FOR DETERMINING ADHESIVENESS

With the growing attention to the adhesion problem in bituminous construction a number of tests were proposed, and some of them were used for the determination of this property. It has been shown how consistency data, may, to a certain extent be used as indicators of the adhesive properties of bituminous materials. Probably, this is the way that the routine physical tests, as appearing in the specifications of most road building agencies, are interpreted by the experienced engineer (if they are not just used for identification). Related to these routine tests and of the same relative value are a number of so-called adhesion tests, which in reality measure some physical properties of the bitumen itself and generally nothing of the interfacial forces. Thus, the ''adhesiveness'' test of Osborne (34) in California actually determines the internal friction of the bituminous material. His apparatus consists of a stationary inner cylinder kept at constant temperature by flowing water, and a revolving outer cylinder, separated from the inner one by a layer of the bitumen to be tested, and obtaining its rotary impulse from a 3kg. weight attached to a wound cord. A similar property is measured by the test of Brown (35). In the Kirschbraun test (36) a wooden ball covered with a piece of silk is immersed in a sample of asphalt which in turn is held in a stationary box. The force required to pull the ball from the bitumen is assumed to be a measure of adhesiveness. After substitution of a mineral ball for the wooden one this test has been recommended as standard method for the determination of adhesiveness by the 5th International Road Congress. Another test of Kirschbraun (37) measured the work required to pull apart a standard ductility brick of asphalt at a specified temperature. In some later work (3) Kirschbraun suggests that the binding properties of bitumen be gauged by considering the relation between ductility and hardness. Wedmore (38) in a qualitative test for binder properties immerses a silver steel rod into the hot bitumen, and withdrawing it when cold measures adhesiveness by the cone formation. A more exact measurement is claimed with an apparatus that consists in essence, of a cylindrical steel mold, filled with the material under test, standing on a very carefully polished steel plate. The mold and the plate are subjected to a slow and steady pull apart, and after separation the percentage of the area of the plate covered by the bitumen in relation to the originally covered area is used as an indicator of adhesiveness. Good adhesion is indicated by a percentage of not less than 90. Raschig (39) observes the time required for 10 of 20 steel balls to fall from an inverted tar surface into which they have been pressed. Values at 23°C. with various tars parallel viscosity somewhat and demonstrate changes in adhesivity over periods of time. The 10 x 10 cm. tar surface on a 12 x 12 cm. metal plate may be used for repeated tests as well as for determination of evaporation losses. The adhesion of films on surfaces is tested by Gardner and Van Heuckeroth (40) by applying a coat of the film substance then placing a piece of silk over it and applying another coat while the first one is still wet. After drying of the film, the silk is cut into strips, which are torn off slowly by means of a tensile strength apparatus. It was found that the film substances did not break away from the silk but from the surface to which they were applied. Another method for measuring the adhesion of dried films is described by Courtney and Wakefield (41). The value and the limitations of these types of tests is evident. If made on a surface different from the one in connection with which the bitumen is going to be used, the tests give only very general indications on the binder properties. They may, however, become more spcific in the hands of the practical man who consciously or subconsciously may be able to interpolate from them through extensive experience gained by intimate contact with the material under test or with similar ones. If, in any of the above tests, a surface is used identical with that to which the bitumen is going to be applied the behavior of the binders under conditions similar to those of the test can be extrapolated. A multitude of possible physical tests for adhesion is enumerated by Bingham (42). A point of greatest importance is that if real adhesion is measured by the test and not as in most cases just a consistency property of the binder, this adhesion of the bitumen is not compared to that of water and aqueous solutions to the same surface. The adhesion values determined by any of these methods are, therefore, reliable in a strict sense only if the system is not exposed to or is well protected from the influence of water and aqueous solutions. Except in the cases of arid and semi-arid regions, most of our roads are exposed to the influence of moisture, and therefore, the affinity or adhesiveness of the aggregate and filler for the bitumen has to be compared with that for water for the evaluation of its service qualities. In recognition of this fact a number of tests have been designed for the determination of the relative affinity of a given material to bitumen and water respectively. In the differential wettability test the mineral is introduced in a two phase bitumen-water system and its preference for either the bitumen or the water phase is observed.

A procedure such as the following can be used (43); 50 ml. of heavy fuel oil (60-70% asphalt content) at 140°F. are placed at the bottom of an eight ounce sample bottle. To this 10 gms. of filler dust passing the 200 mesh sieve are added. The bottle is then placed in a water bath, which is maintained at 140°F. and the mixture is stirred for five minutes with a mechanical stirrer rotating with a speed of 1500 r.p.m. Hereafter, 100 ml. of distilled water at 140°F. is added and the mixture is stirred for five more minutes. Then the phases are allowed to separate and the amount of dust on the bottom of the jar is estimated and recorded as per cent of the total dust content. 0 per cent is supposed to indicate a perfectly satisfactory filler, 100 per cent an entirely unsatisfactory one. Separation up to 25 per cent may be tolerated.

Because of complex surface phenomena the results of this test do not always lend themselves to easy interpretation. The foremost criticism against this type of test is that the bitumen has not yet had the same chance to attain its optimum adhesion to the mineral matter (by surface orientation of its active constituents or by chemical reaction) as it usually has in a well built bituminous pavement before the water exerts its influence.

This criticism also holds for the test of Davis Jr. (44), whereby water is worked into a road oil paving mix. The amount of water which may be worked into the putty and the ease with which it may replace the bituminous films is used as an indicator of the adhesiveness of the bitumen to the mineral materials. Therefore, those tests are better in which the mineral aggregate or filler is first coated with bitumen, which is permitted to cure for a definite period of time before it is submitted to the attack of water. This can be done in the swell test (45) in which a compacted (and cured) specimen of oil mixed aggregate in representative proportions and gradation is immersed in water for 24 hours and the swell noted as indicative of the resistance of the bituminous films to replacement by water. In the DIN Wasserlagerungs-Method a bituminous film of a definite size is applied. Poor adhesiveness is indicated by marked contraction. In the "jar test" of Hughes (46), the stones are coated with a film of binder, placed in a jar and covered with water. Displacement of the binder is noted by visual observation. Nicholson (47) shakes bitumen coated sands and rock powders for one hour in water of 140°F. and determines visually the loss of the coating. The test can be improved by softening the bituminous coating with the help of an added solvent for the bitumen. An amount equal to the weight of bitumen is used. There does not seem to exist any major objection to this type of test, as long as a certain curing period is allowed to the bituminous film to complete its adsorption arrangements. Dahlberg (48) proposes that adhesion tests be made in water of 100°C, 70°C and 50°C and that the results be extrapolated to a temperature of –10°C. The method described by Nicholson is used in the following way by the Bureau of Public Roads:

"A weighed sample of the material is mixed with approximately 5% by weight of the asphaltic product under investigation. If the asphaltic product is a liquid at normal atmospheric temperature, the mixture is then spread out in a thin layer and allowed to air season overnight.

A 50-gram sample of the mixture is separated as nearly as possible into individual fragments or small clumps and placed in a 250 cc. Erlenmeyer flask with 175 cc. of distilled water.

The flask and contents is then placed in the frame of the agitating machine (see page 43, January, 1932 Proceedings, the Association of Asphalt Paving Technologists), and rotated at a speed of 45 r.p.m. for a period of 15 minutes at room temperature. At the end of this period the sample is then examined for evidence of film stripping and the observation recorded.

Rotation of the sample for an additional 15 minutes at room temperature is then made and notation made of any film stripping which may have occurred. If little or no stripping has been noted at room temperature, the test is repeated for another period of 15 minutes at 100°F, the water bath being maintained at this temperature throughout the period of test.

If little or no stripping has been noted at 100°F, the test is then repeated at 120°F.

It is suggested that, irrespective of the extent of stripping which may have occurred at lower temperatures, the entire procedure involving a total agitation of one hour be carried through.

The test is not quantitative in nature and observations as to extent of stripping may vary with individual operators. In line with action taken at the meeting of the Project Committee, it is therefore suggested that the following general classification be adopted for reporting observations at the end of each period of agitation.

1. No stripping
2. Slight stripping
3. Bad stripping

Note: It is suggested that if apparently 25% or more of the surface area of the aggregate particles has been stripped, the results be reported as bad stripping.''

At this point a few general remarks on ''testing'' appear to be desirable. Since testing is an examination of the fitness of a material for a certain purpose it should subject the material to the maximum strain and usage to be expected in service. On the other hand, the testing should not consume too long a period of time. These requirements can be met relatively easily with standard construction materials of well defined physical properties such as steel, brick, building stones, etc. The testing becomes more difficult if the material acquires its maximum stability only after a period of actual service and if in service it is not only exposed to definite stresses but also to a slow but constant and effective physico-chemical and chemical attack. First the more simple question about the time of contact and curing before testing arises. This can be answered experimentally. The more important problem is to devise a test which duplicates in a short time the effect of long time exposure to slow acting agencies. In a simple chemical system where only one reaction or its reverse may occur it is relatively simple to speed up or retard this reaction by changes in temperature or/and in concentrations. The situation is quite different in a multicomponent system where a number of different reactions may occur, the speed and equilibrium conditions of which may be changed to different extents by changes in temperature, concentration and composition. Since the bituminous systems under consideration are of such a complex nature as to render impossible a reliable prediction of what happens under different conditions, any accelerated test can neither be accepted nor rejected on a purely theoretcial extrapolation, but the identity or similarity of its short time reaction with the longtime exposure under service conditions must be experimentally established. Of course, this experimental verification must be backed up by theoretical analysis to prove that the similar effects have been brought about by identical or at least closely related phenomena. At any rate the testing conditions should be as close as possible to the natural service conditions and the acceleration of the testing should not be caused by introduction of a new variable. This fact should be kept in mind in the evaluation of data obtained by such chemical tests as that of Riedel and Weber.

In this method, which has been included in the DIN as a recommendation, the mineral to be tested is pulverized to a grain size K_2 (passing DIN sieve No. 10 with 100 mesh per cm^2. and being retained by sieve No. 90 with 900 mesh per cm^2). Seventy-one units per volume of this powder are mixed with twenty nine units of hot liquid bitumen. After cooling (and eventually curing) the mixture is boiled for one minute in water. If this treatment suffices to separate the bitumen from the mineral the latter is called hydrophilic, if it does not suffice the mineral is called hydrophobic. The degree of hydrophobicity is measured by the resistance of the bituminous films against stripping when boiled for one minute in sodium carbonate solutions of varying concentrations. The numerical value for adhesiveness is then empirically defined by the concentration of that sodium carbonate solution at which stripping of the bituminous film occurs. This definition is given in the following table.

System for Adhesion Values

Concentration of Na_2CO_3	Adhesiveness	Character of Mineral
0	0	Hydrophil
m/256	1	Hydrophob
m/128	2	"
m/64	3	"
m/32	4	"
m/16	5	"
m/8	6	"
m/4	7	"
m/2	8	"
m/1	9	"
No separation	10	"

The testing method of Riedel and Weber received criticism primarily for following reasons:

(1) The behavior of fresh surfaces originated by pulverization is different from that of the aged (and probably weathered aggregate,

(2) The action of water at normal boiling temperature is different in kind from that at normal road temperatures,

(3) The action of boiling Na_2CO_3 solutions is different in kind from that of plain water,

(4) Because of differences in fluidity at different temperatures of different bituminous materials, the action of the boiling solutions may be a function not only of adhesion but also of consistency and flow properties.

It was also stated that:

(1) The test does not bring out any difference between the coating properties of different bituminous materials for the same aggregate, while such a difference undoubtedly exists in practice. (Nussel & Neumann (49) found such differences with the test, and also Riedel's own work indicates these, but this fact is minimized by Riedel and Weber).

(2) Results obtained with R & W test differ fundamentally from those obtained with the water immersion test (DIN-Wasserlagerungs methods) which latter test has proven itself as a reliable indicator of the behavior of bituminous material in service.

(3) The theory of the R & W test does not explain the change of the adhesive character of a certain bitumen by the addition of fillers.

Concerning these objections, it must be kept in mind that the test is an accelerated one and that, according to the discussion above, it is ipso facto open to criticism. With the benefit of acceleration, generally, goes the disadvantage of a certain indeterminacy of the results. Although there appears to be little reason why, in the system under consideration, water at 100°C should exert an effect which is fundamentally different from that at 50°C or 70°C it appears to be worthwhile to use not one test temperature alone but if possible several temperatures as done by the Bureau of Public Roads. The objections against the use of Na_2CO_3 solutions appear to be fundamental and worthy of a thorough going analysis. It is surprising that such an exponent of chemical adhesion as Riedel has neglected to avail himself of the data accumulated in the scientific literature on the change of the water affinity of minerals caused by a variation of the exchangeable ions. The sodium ion is especially active in changing the surface of minerals to a greater hydrophily. Therefore, its introduction into the system is especially objectionable, since, during the testing process the surface properties of the minerals are liable to be changed by it to quite an extent. From this standpoint of the change of the physico-chemical properties of the mineral by ionic exchange potassium carbonate solutions would appear to be much less objectionable (50). But there still remains the criticism that saponifiable and hydrolyzable constituents of the bitumen which normally improve its adhesiveness are changed by alkali into emulsifying agents which aid in the stripping of the bituminous films. This objection appears to be corroberated by Riedel and Weber's own data whch show that the alkali concentration required for the stripping effect is a function of the thickness of the bituminous film. This criticism should hold especially in those cases in which saponifiable materials have been added to the original bitumen to enhance its adhesiveness. Such admixtures are described in a number of recent patents (51).

The objection against the pulverizing of the mineral appears to be important if the surface character of the natural aggregate has been changed by weathering or (and) by adsorption of foreign substances. At any rate it is preferable to test the aggregate as it is used on the road and not in a different state of subdivision. Part of the criticism raised against Riedel and Webers test method has been refuted by the originator themselves and also by Geissler (52). The latter states that examination of the methods by various investigators has shown, in general, satisfactory reproducibility and good agreement with practice. Molls (53) view that the size of the aggregate has an influence on the results is claimed to be unsubstantiated, while in reply to Dahlberg's objection it is stated that the results at room temperature agree exactly with the results obtained at 100°C and that the latter temperature was only adopted in order to speed up the test. From an examination of a number of stones and binders it is concluded that the adhesion of asphaltic or tar bitumen to a given stone differs only slightly, but that stones of the same type but from different sources may show entirely different behavior. Adhesion is stated, as a rule, to increase with time, and it is believed that the chemical composition of the aggregate is the principal factor of influence. Swelling of the binder-stone mixture in water is believed to be indirectly related to adhesion, since swelling occurs in mixtures of hydrophilic stones, whereas hydrophobic stone mixtures swell only slightly; this is thought to be due to the adsorption of a film of water between the aggregate and the bituminous coat. Even if we can accept Geissler's work as far as stated, neither he nor anybody else has yet succeeded in refuting the objection against the use of alkaline solutions. It is apparent that the exact meaning of testing of adhesiveness by means of water and aqueous solutions is still in a controversial state. But also there appears no fundamental reason for the pessimism of Hermann (54) who believes that the impossibility of eliminating such factors as moisture and surface dust on the stone and the pressure of swelling material in stone or binder prevents the practical use of adhesivity tests. On the other hand it is logical that testing methods should be modified for materials which are subjected to special conditions as in alkali soils or in sugar beet regions, etc. to render the results valuable as service indicators. In these cases the specimens should be tested with solutions of the same composition as those encountered on location. Data of importance in this connection have been accumulated by Riedel and Weber and by Jachzel (55). Oberbach (56) in an authoritative discussion on the practical problem of adhesiveness concludes that:

(1) The interaction of bitumen and mineral surfaces in a function of the mechanical, crystalline and other surface properties of the mineral and of the chemical composition and the physical characteristics of the bitumen. The water submersion

test should be used to decide what type of bitumen should be chosen for a given aggregate.

(2) The greatest danger of too great a reliance on hydrophobic or hydrophilic character (as determined by the R & W or any other adhesiveness test) of an aggregate resides in the potential neglect of other factors of great importance in bituminous road construction. Thus, at least under north-European conditions, the service life of a bituminous pavement depends primarily upon the exclusion of water and air from the pavement. These agencies together with actinic activation and, probably, with the catalytic assistance of some mineral surfaces destroy the binder properties of the bitumen. Therefore, as great a resistance as possible to the diffusion of water and air should be attempted in any bituminous construction.

In this connection the observation of Oberbach gains importance that the problem of adhesiveness was practically nonexistant before the advent of cutbacks and emulsions. It appears probable, that the greater porosity of pavements constructed with the help of these materials resulted in a greater susceptibility of the bitumen to the destructive action of the elements. The influence of a large internal surface on the weathering of tar-bitumen was shown by Rhodes (57). Consequently open type pavements should either be avoided or a highly weathering resistant bitumen should be used as binder. The findings of Oberbach agree with the experiences in Missouri (32). A critical perusal of the work on the adhesion of bitumen to mineral surfaces gives a great probability if not practical certainty to following arguments:

(1) The problem of adhesiveness is only a part of the binder problem. Another part is connected with the weathering resistance of the bitumen in the pavement as affected by its chemical composition and the effect of the proximity of the mineral surfaces involved, and the accessibility to weathering agents. The consistency properties of the bitumen also play a great role in the effectiveness as a binder, since on one hand in the plastic state a material with greater viscosity possesses a greater resistance to dislocation; on the other hand if a binder becomes hard and brittle as a result of low temperature or of chemical dispersed in the moisture on the pavement, a difference in the expansion and contraction coefficients of the mineral, the adsorbed binder film, and the bulk of the binder may result in a breaking away of the bulk of the binder from

the adsorbed film, or of the bituminous film from the mineral and thus open the pavement to the attack of outside agents and expose the surface of the mineral particles. What the contraction of an adhesive film on a mineral surface can achieve is well illustrated by the contraction of a gelatin film on a glass plate which can effect a breaking off of fine glass particles resulting in a "frosted" surface. The importance of a small pore space in connection with the attack of weathering agents has a parallel in the case of Portland Cement concrete where Wiegner (58) has shown that its resistance to the chemical attack of moor waters is not so much a function of the chemical composition of the concrete but rather of its pore space.

(2) The theoretically obtainable adhesion of bitumen to mineral surfaces apparently depends:

(a) On the mechanical and surface-chemical properties of the mineral surface, and

(b) On the chemical (notably polar) character of the constituents of the bitumen.

The adhesion obtained in practice is in addition, a function of the condition and time of contact between the bitumen and the mineral surface. A recent specification of the California Highway Department appears to consider the asphaltenes in excess of 6% (determined with 80-82° Be Western Petroleum ether) only as fillers and not as an integral part of the bitumen. This concept seems to be diametrically opposite to that of most American and European investigators who appreciate the asphaltenes as an important binder constituent with beneficial effect on adhesion. In the light of modern work showing the importance of the filler in modifying the adhesion properties of bitumen to aggregate (59) the difference of these concepts may reside only in words and definitions but not in facts.

IMPROVING THE BINDER PROPERTIES OF BITUMINOUS MATERIALS

With the gradual recognition of the factors determining the adhesion of bituminous films to mineral materials attempts for the improvement of the bituminous binders have gone hand in hand with those for the improvement of the surface properties of the aggregates. Addition-substances to the bitumen are in general of a polar nature and consist of materials such as fatty, waxy, naphthenic or resinous acids and their soaps with mono- and more-valent cations, polmerizing and polymerized substances, such as polymerized, polyvinylchloride, anilinealdehyde and phenol-aldehyde mixtures and resins, "Nitrite" and chlorinated rubber et similia (51). The surface character of minerals can be changed by precoating with such organic substances as mentioned as additions to bituminous binders or with such mineral coatings as lime, Portland cement, ironoxide, etc., for which bitumen has a great affinity, or by base exchange (60). In this connection it should not be forgotten that there is an influence of the filler in the binder on the adhesion of the latter to an aggregate; consequently selection of the right type of asphaltic filler may improve the binder qualities of the bitumen (59). A more complete enumeration of substances which are used or claimed to improve the binder qualities of bituminous materials are contained in a recent patent survey (51).

OUTLOOK

The above survey appears to bring out the fact that enough scientific and practical data have been accumulated by the workers in this field to enable the engineer to design good pavements with bituminous binders. Of course, the requisite for this is that the accumulated knowledge is available to the engineer in the form of some such resume as was attempted here, and that the engineer has a well founded background in the basic principles concerned. The latter will help him also in the understanding of the practical difficulties of the construction engineer and will thus make for a better cooperation between the office and the field man in the great object of constructing better and more economical roads.

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Developments of Intermediate Type Pavements in Mississippi.

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The first year of Mississippi's $42,000,000.00 Road Program closed on May 19th., 1937, with Projects totaling $28,000,000.00 awarded and under contract. It is believed that this constitutes a record of some sort, as a large percentage of these Projects were for grading and drainage on new alignment, necessitating much field and office work before the plans were completed.

Under this Program, Mississippi's priority system will be left about 75% complete, and the secondary system, comprising important State routes and Federal Aid routes of relative low traffic volume, will be about 40% complete.

It is the purpose of this paper to discuss briefly the pavement types and subgrades on this Secondary System in Mississippi, these Secondary roads having a traffic volume per 24-hour day of from 800 to 3000 vehicles.

To a person unfamiliar with Mississippi, a trip through the State would impress him with the large deposits of sand, sand clay, sand gravel and clay gravel with which the State is studded. Further investigation would reveal that while Nature has dealt mineral aggregates with a lavish hand, she scattered soils unsuitable for subgrades with wild abandon. Soils having a volume change from the Field Moisture Equivalent of 80 are not uncommon, and all of the unholy combinations possible are represented, three and four classifications being found frequently in one roadway Station. The Western edge of the State contains unlimited quantities of Loess soil, 85% of which, when pulverized, will pass a #400 mesh sieve. No rock deposits of commercial value are found in Mississippi.

Realizing that no pavement can survive when placed on an inadequate base, a satisfactory subgrade is obtained by various means, the most economical deciding the method used. This is accomplished by building the top twelve to eighteen inches of subgrade of selected sand clay topping, stabilization with either sand or bitumen or building a compacted gravel sub-base. Frequently soils of such plastic nature are encountered that tile drains are of no benefit, and such soils have to be removed and replaced when encountered in cuts. Treatment of the subgrade is, therefore, included in the grading and drainage project, and a light surface application of gravel applied to accommodate traffic until paving operations begin.

The rainfall in Mississippi averages fifty-five inches per year, which is equally distributed over nine months of the year. Due to this rainfall, a bituminous material that has emulsifiable characteristics has proven unsatisfactory, and as a consequence, the slow curing and medium curing cutbacks are not satisfactory. Emulsions are also effected by this rainfall. As the rapid curing cutbacks and asphalt cements have from past experience proven the best bituminous binders, these are the preferred bitumens.

A detailed survey of local materials has progressed to the extent that the available aggregates are known, and samples are taken to our Research Laboratory, where tests are made to determine their suitability in a design mix without the addition of any other material. A Hubbard Fields Stability Testing Machine is used to test the design mix mortars, with pavements which have given satisfactory traffic service.

The minimum stability requirements have been determined by investigation of the stability of roads that have been under traffic as long as three years, and from these roads, it is found that a stability of 300 lbs. per square inch will satisfactorily carry traffic. This applies to sand mixes where all of the material passes the No. 10 mesh sieve. On materials containing coarse aggregates, a stability test is made on the mortar only, as accurate results can not be obtained with coarse materials. Asphalt cement is used in these tests to obtain immediate results.

From the void theory, the approximate asphalt content is determined, and tests are made using several penetration asphalts. Somewhat contrary to the Hubbard Fields theory that relative high stabilities are desirable, our tests and pavements previously laid, indicate that a minimum stability and a maximum flexibility are desirable.

This theory is substantiated by the behaviour of a 4½" asphaltic concrete project which was laid four years ago on a base, inadequately stabilized. The three inch asphaltic concrete base course had a density of 90% of the maximum theoretical with only 2% of the mass passing the No. 200 mesh sieve, while the 1½ inch Topeka surface had a density of 96% of the maximum theoretical. Due to the high volume change in the subbase, there is constant movement in the slab, with the result that the rigid dense surface course has developed considerable cracking, the black base being free from cracks. 40-50 penetration asphalt was used throughout this pavement.

As a measure of the desirable flexibility to design for, bend test was devised by H. O. Thompson, Testing Engineer. As this test is made at a temperature of 40° F. and the stability test at 140° F., it is felt that a pavement stable at 140° F. and yet still flexible at 40° F. is the ideal to strive for. To test this surmise, a test track fourteen feet in diameter, similar to the track at Arlington Farms Laboratory, is being constructed, which will provide an additional check on our laboratory designs.

Below are given the gradations of several deposits of materials, as they occur in quantity, available to one or more Projects. This materially determines the type and composite mix requirements that will be used on each Project:

		#1	#2	#3
Pass. 1" Sieve —	Ret. on ½" Sieve	0.0	1.7	0.0
" ½" " —	Ret. on #4 Mesh Sieve	15.2	35.9	0.0
" #4 Mesh " —	" " #10 " "	13.1	16.5	0.4
" #10 " " —	" " #40 " "	31.3	23.6	16.2
" #40 " " —	" " #80 " "	37.8	12.2	76.0
" #80 " " —	" " #200 " "	2.5	9.9	7.1
Pass. #200 Mesh Sieve		0.08	0.2	0.3

Sample No. 1 is a deposit of waste material which has accumulated through years of processing concrete aggregate and contains over 100,000 cu. yds. This deposit is available to thirty miles of newly graded Projects.

The addition of 5% of a 72 penetration asphalt to the pit run material gave an average stability of 900 lbs. per square inch and density of 82% of the theoretical maximum. Water confined to the surface of this specimen for two months was absorbed only two-tenths of one per cent. The surface, however, was highly abrasive and could not be used for a surface course without a seal.

As the thickness of these low stability pavements as determined by traffic, should not be less than five inches, it was decided to use this design for the base course and construct it 3½″ in thickness. This same design with the addition of approximately 8% Loess soil for filler and an asphalt content of 8.2% gave an average stability of 1500 pounds, which is satisfactory for the surface course. The base course mixture is slightly less flexible than the surface course, which is desirable. It is interesting to note that Loess as a filler produces a much more flexible pavement than do any of the commercial fillers. This checks experiments made on fillers by the U. S. Engineers at New Orleans.

Sample No. 2 is a sand gravel deposit of unlimited quantity from which eleven miles of road has just been completed. The Project as awarded required a 4″ Asphaltic Concrete Base Course and a 1″ Asphaltic Concrete Course (Topeka Type), the composition formula being revised to use this material. It was found that a 4″ base course is difficult to roll satisfactorily, and the Plans have, therefore, been revised to decrease the base courses to 3½″ and increase the surface courses to 1½″ where coarse aggregate is used.

Sample No. 3 has been obtained from a sand bar in a small river, and the contemplated design will be similar to that of Sample No. 1.

On all samples, the mixing temperature has been studied, and it is now the policy of this Department to require as low a mixing temperature as is workable. This, we believe, will materially prolong the life of the pavement. Each Project Engineer is furnished with his minimum base and surface course Specific Gravities and from cores taken twice a day on both base and surface course, the desired density is obtained.

From our studies on roads previously constructed as well as our Laboratory experiments, we have reached the following conclusions:

1. Road Mix Sand Asphalts on an adequate base satisfactorily carry traffic of 500 to 1000 vehicles per day, yet show no stability under a Hubbard Fields Stability Machine for several months.

2. That the more satisfactory Projects have, in all cases, had a surface course but slightly more rigid than the base course. There is a point on the Stability curve of maximum stability and flexibility, and it is to this point that our designs are made.

3. That on sub-bases of high volume change, even though plated with twelve to eighteen inches of selected material, the flexibility is equally as desirable as high stability.

4. That softer asphalts increase flexibility with a corresponding decrease in Stability. The most desirable penetration has not yet been determined to our satisfaction.

5. That the actual density of a pavement is not particularly important, as tests on specimens having a density as low as 70% of the theoretical, show them to be water repellant. Stable mixes were of course used in this test.

6. That the thicker mats, while of higher initial cost than the surface treatments and road mixes, show a decidedly lower maintenance cost. This is thought due to our high annual rainfall.

Conclusion: With these results and conclusions, it is felt that very satisfactory results are being obtained, and that the design could and should be brought to the available local aggregate. Additional experiments are being made, and from them it is hoped will result roads of high value and low cost.

Some Basic Factors and Their Effect on the Design of Bituminous Mixtures

By

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Any attempt to discuss fundamentals or basic factors seem to lead sooner or later to a definition of terms and a consideration of nomenclature. One of the necessary steps in the process of analysis is the grouping together of related phenomena or observations. Many observations and much valuable data have not been correlated because they seem to apply to unrelated fields. It is here that the question of nomenclature requires scrutiny as it is a fairly common habit to accept without question an object or phenomenon which has been accorded a name. The engineer is as guilty as the layman in assuming that he knows a great deal about a matter because he knows what to call it.

If all pavements composed of mineral aggregate bound together with some asphaltic product were considered under the one heading of bituminous mixtures, I do not doubt that we would have fewer differences of opinion as to what constitutes fundamentals. In a condition, however, where we have distinctive names, each of which conveys a somewhat different impression and covers a different group of experiences, we have wide divergences of ideas and much evidence that appears to be contradictory. Asphalt paving technology has been developed by a group of men who are individually acquainted with asphalt macadam, sheet asphalt, Topeka, asphalt concrete, rock asphalt, Bitulithic, Warrenite, Willite, and other patented types too numerous to mention, to say nothing of the more recent oil mixes, plant and road mix type, armor coat, multiple lift, retread, etc. These various names do have their useful purpose, but they also tend to leave our knowledge in separate pigeon holes. If all the known data are assembled and correlated, it is possible to detect any general principles which apply to all types. For example, one generalization common to all bituminous pavements is that they are composed of two essential ingredients—one a granular mineral aggregate and the other a liquid bituminous product of variable viscosity. The second universal condition is that all of these pavements, regardless of composition, must carry similar moving loads in the form of motor traffic on rubber tired wheels. The fact that bituminous pavements coming under any one of the above classifications can be constructed to carry considerable traffic without distortion indicates that the fundamental requisites for stability are sufficiently realized in every stable bituminous road surface regardless of type or designation.

By this simple process, it is then possible to decide which properties or factors are of fundamental importance and which are not. This approach immediately eliminates any particular gradation of aggregates as being essential to stability. It also indicates that the viscosity of the bituminous binder may vary greatly without losing the necessary stability. By considering all types to determine those requirements which are absolutely necessary, we can eliminate from consideration any particular aggregate grading, consistency of the bituminous binder, necessity for dense mixtures, the need for filler dust, hardness of aggregates, and any other condition or ingredient which is peculiar to some one type of bituminous pavement and does not exist in others.

It is realized, of course, that each of the various types of asphalt pavement have their individual advantages and disadvantages, and beyond doubt we will continue to see asphaltic materials used in many different types of pavement construction, and for sound engineering reasons. For example, sheet asphalt pavements have the advantage in construction for securing smooth riding qualities, but frequently develop a dangerous skid hazard. Macadam construction, on the other hand, is nearly always safe when wet, but smooth riding qualities are difficult to attain. There are many such pros and cons which might be enumerated at great length for the various types, and there is relative economy always to be considered.

In this light, **it appears that a so-called fundamental, i.e. a basic essential requirement, is restricted to a particular property of the finished pavement.** In other words, a fundamental requirement for stability may not be a fundamental requirement for impermeability. Steps to provide a workable mixture will not necessarily enhance the stability, and so on. Therefore, each esteemed property of the pavement must be secured by attention to its peculiar fundamentals. These various basic considerations are sometimes in direct conflict.

As an illustration of the application of fundamentals to a particular problem, the matter of stability will be discussed in some detail.

One property possessed by all masses of granular materials, regardless of size or shape, is some degree of internal friction which tends to resist movement or deformation of the total mass. The frictional resistance of solid particles under a given condition varies directly with the pressure to which they are subjected, is relatively independent of the speed of action, and independent of the area in contact. The observation that bituminous mixtures may develop stability regardless of variations in grading of the mineral aggregate is entirely compatible with this principle.

From this law it could have been deduced that bituminous pavements would be benefited by any increase in consolidation. The more effective the consolidation that is developed in the pavement, the greater will be the resistance to distortion. Experimental evidence and actual experience confirms this assumption.

Frictional resistance between two solid bodies may be lessened by separating them with a film of viscous liquid. Viscosity is a highly important quality of all lubricating oils. If the solid particles are completely separated by a viscous liquid, any resistance to movement is then due only to the flow characteristics of the liquid, in this case the asphalt, and the law of liquid friction states that the resistance to movement of a viscous liquid between two parallel plates is relatively independent of the pressure, but varies directly with the speed of action and directly with the areas in contact. Examination of all types of bituminous mixtures offers no contradiction to this statement. However, a mixture of mineral aggregate and asphaltic binder forms a mass whose deformation characteristics will follow neither set of laws exactly, inasmuch as the surfaces in contact are neither wholly dry nor completely lubricated, and the difference between instability and stability of asphaltic pavements is almost without exception the difference between lubricated and unlubricated surfaces. Lubrication of a pavement may be brought about by a sufficient amount of asphalt, oil, water, or a combination of two or more liquids, and is frequently enhanced by an excess of filler having unctuous characteristics.

From a consideration of this one quality of stability, it can now be concluded that bituminous mixtures possess only two fundamental properties which combine to produce stability of the mixture. One property is frictional resistance between the solid particles of mineral aggregate, and the other is frictional resistance in the films of bituminous binder. Liquid friction contributed by the asphalt may be variously designated as viscosity, cohesion, or tensile strength.

Both liquid and solid friction are variable, and in a pavement mixture may vary independently of each other, as the conditions which affect one may affect the other in an unrelated manner. For example, frictional resistance between the rock particles is enhanced by rough surfaces and angularity and by the degree of consolidation. It is not greatly affected by changes in grading or by density of the mass. Cohesion due to the asphalt is to some extent influenced by the character of particle surfaces, increases generally with increased surface area, and reaches its maximum for a given asphalt at the point of maximum density of the mixture. In bituminous pavements, the cohesion varies in a wide range with the temperature, with the consistency of the asphalt, and with the presence or absence of fine dust or filler.

Unfortunately, these two basic factors, which will henceforth be called simply friction and cohesion, do not contribute to stability either **in equal degree or in kind,** and it becomes necessary to decide whether to aim at increasing the friction of the cohesion or a combination of both, when designing the bituminous pavement.

High frictional resistance is obtained by selecting aggregates having a sandpaper-like surface texture, and with the quantity of asphalt maintained definitely below the total void volume. The percentage of voids which may be filled with asphalt is positively a variable, and differs for each type of grading and asphalt used. In other words, knowing only the voids in a mixture and with no other information, it is not possible to determine the quantity of asphalt binder which will give the best results.

High cohesional strength can be obtained by use of low penetration asphalts and by increasing the quantity of fine sand and filler dust. Sheet asphalt mixtures, for example, develop very much higher cohesion than is the case with asphalt concrete Asphalt concrete surface mixtures containing filler dust show much higher tensile strength than do base and leveling course mixtures without filler.

In order to decide how much of these two properties to incorporate in the design of a pavement, it is necessary to form some idea of their relative importance. For this purpose, the California Laboratory uses two separate instruments. The Stabilometer* is sensitive primarily to internal friction of the mixture and is affected to only a small degree by the cohesion. The other instrument, the Cohesiometer*, measures primarily the cohesion of a compacted specimen, and is affected not at all by the frictional resistance of the aggregate. For example, a sample sheet asphalt mixture compacted equivalent to pavement density has shown no difference in the Stabilometer value when tested at any temperature between 70° and 140° F. The same specimen in the Cohesiometer, however, showed a great increase in cohesion at colder temperatures.

These two instruments have been used to test samples taken from existing pavements representing practically every type of bituminous surface, with the exception of asphalt macadam using very large aggregate. The conclusion is inescapable that cohesion tests alone cannot be correlated with pavement performance under traffic. Samples of fuel oil mixtures that have withstood traffic for 10 years without any sign of deformation or instability, when tested in the Cohesiometer at 140° F. show values so low as to be barely measurable.

In our scale for measuring cohesion, the highest obtainable values are approximately 1000. In this scale, many stable fuel oil mixes commonly range from 50 to 100, whereas asphalt concrete and sheet asphalt specimens ranging as high as 500 have been taken from pavements that had distorted badly under traffic. It is true, however, that when cohesion values are below 50, there is a tendency for the surface to scuff or tear under traffic.

On the other hand, there is a distinct relationship between low Stabilometer values and unstable pavements. It therefore appears that the most important basic factor in securing the stability of a bituminous mixture is to maintain the frictional resistance between the aggregate particles sufficiently high.

Thus far in the discussion we have been dealing primarily with the property of stability, and I may say here that I agree that there has been a tendency to exaggerate the importance of stability at the expense of other necessary properties of the pavement. I believe that this tendency always occurs when we have means of measuring and expressing some particular quality, and lack means for assigning a numerical value to others.

Everyone dealing with the design of pavements should realize that the best design is not simply a matter of getting the greatest stability or considering any one quality to the exclusion of others. The pavement should be regarded as a structure, and when planning a structure the engineer usually has more than one property to be incorporated, and must include all the essential needs as economically and as efficiently as possible. A good pavement should satisfy many requirements, some of which might be enumerated here. For the bituminous pavement, sufficient stability and freedom from raveling; resistance to weather action, including moisture, heat and cold, oxidation; a non-skid surface to eliminate driving hazards; a tight impermeable surface to protect the subgrade when necessary; or sufficient porosity to permit suspiration of ground water when that is necessary. The pavement should utilize economically the most available aggregates and lend itself readily to construction of a smooth riding surface with the available equipment.

In order to incorporate all of these desirable properties in one simple mixture, it is necessary for the designer to know something about the basic factors and how each particular effect can be achieved, and most important, to what extent he might compromise the several considerations. For example, in order to resist weather action, a relatively rich mixture is desirable.

The heavier the film coating on the particles of aggregate, the greater will be the resistance to aging and deterioration of the asphalt. However, if this consideration is allowed to dominate the design, there is considerable danger that an unstable mix will be developed. Resistance to abrasion, raveling, and impact also increases as the quantity of asphalt is increased. But unfortunately, while we are improving the mixture to increase cohesion and ''malleability'' which are in themselves desirable, increasing the thickness of lubricating films beyond a certain point will simultaneously reduce the friction on which stability so largely depends.

When we approach the subject of durability and weather resistance, we are entering a large and complex field which merits the attention of a specialist in this line. It is no longer simply a matter of mechanics and fixed proportions; it is necessary to consider obscure properties of both the mineral aggregate and the asphalt. Sad to relate, all asphalts do not have equal ability to resist detrimental change and all mineral aggregates do not have the capacity to retain a coating of asphalt in the presence of water. It is hardly within the scope of this paper to enter into a discussion of the ramifications of hydrophilic and hydrophobic aggregates, as a great deal has already been written, and much work remains to be done on this subject. This is also true of the important properties of the various oils and asphalts. Whether an asphalt should be heterogeneous or homogeneous, and whether ductility at 77° F. is or is not important are matters which may ultimately be thrashed out.

The weathering of asphalts and their susceptibility to hardening during the mixing process and after being incorporated in the pavement is a subject now receiving considerable attention, and its importance can hardly be over-estimated.† It appears, however, that separate tests on the various ingredients of a mixture can easily be misleading. I think that this has been well demonstrated throughout the history of asphalt tests, and it seems that after many years of applying the standard identification tests we are still not sure whether a given asphaltic product will make a good road or not.

I am tempted to venture into the hazardous field of prophecy, and express the opinion that in all liklihood the only satisfactory tests for either asphalts or aggregates will be performed after mixing the two materials in approximately the same proportions as are used in actual practice. It should thus be possible to detect the tendency of an asphalt toward premature aging and brittleness, and it is already possible to detect hydrophilic tendencies of aggregates with a fair degree of assurance by means of tests on the complete mixture, although procedures for this purpose no doubt will be improved.

If the pavement mixture is to be rendered tight or impermeable so that moisture will not readily pass through, the most effective means is to provide a dense graded mixture in which the **pore sizes** are small enough to prevent the passage of water. I might call attention to the fact that the size of the pores cannot be determined by measuring the void volume. A fairly dense pavement with a few large pores will permit the passage of water, whereas a fine graded mixture moderately well oiled will not, even though the relative density is not particularly high.

Briefly, then, the requirements of a pavement and the important fundamentals might be summarized as follows: For the best stability, a harsh, crushed stone with some gradation, mixed with only sufficient asphalt to permit high compaction with the means available. For greatest resistance to abrasion, raveling, aging, and deterioration, and imperviousness to water, a high asphalt content, broadly speaking, the richer the better. For impermeability, a uniformly graded mixture with a sufficient quantity of fine sand (fine sand is more important than filler dust). For non-skid surfaces, a large quantity of the maximum size aggregate within the size limits used. For workability and freedom from segregation, a uniformly graded aggregate. To reduce the above factors to as simple a consideration as possible, it seems to be the best rule to use a dense, uniformly graded mixture without an excess of dust and add as much oil or asphalt as the mixture will tolerate without losing stability.

FOOTNOTES

† **Experimental Asphalt Concrete Pavement Using Hard and Soft Asphalt.**

* For description see ''Role of the Laboratory in the Preliminary Investigation and Control of Materials for Low Cost Bituminous Pavements'' by T. E. Stanton and F. N. Hveem, published in the Proceedings of the Fourteenth Annual Meeting of the Highway Research Board, December, 1934, Part II.

In view of the rapidly accumulating evidence pointing to the detrimental effect of hardening and oxidizing of asphaltic cement in service, California has recently constructed several miles of experimental pavement in which asphalts of varying penetration were used in standard asphalt concrete construction. Each section was approximately one-half mile in length. The asphalts used included 55, 76, 110, 170, and 225+ penetration, this latter grade being designated as 90-95 road oil.

The standard construction procedures were followed throughout, with the exception that plant mixing temperatures were reduced with the softer grades of asphalt, and in some cases final rolling operations were delayed one or two days after the material was spread. The percentage of asphalt was reduced from 5.3 in the case of the 50-60 grade to 4.8 with the 90-95 road oil.

This road has been under very heavy traffic for about two months. The temperatures in this area are quite high, frequently reaching 110° F. At the present time, it is not possible for the casual observer to detect any difference in appearance between the several types used.

No construction difficulties were encountered, with the exception that with the very soft grades it was necessary to delay the final rolling operations until the following morning, when the pavement was cool. Stabilometer tests on all types of mixture were amply high, and there seems to be little reason to fear any lack of stability in the pavement. Whether or not this pavement will have any greater resistance to cracking can only be determined with time. However, thus far results appear to be quite encouraging.

Developments in the Fundamentals of Bituminous Construction

By

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INTRODUCTION

The construction of low-cost bituminous surfaces in Nebraska was started in 1928 when six short sections of highway totaling about six and one-half miles in length were surfaced by mixing slow-curing asphaltic oil with the available aggregates including material existing in the roadbed. Each year, since this meager beginning, the construction program has provided for a rapid increase in the mileage of bituminous surfaces. At the end of the present construction season, Nebraska's highways will offer 1,200 miles of this type of pavement for the use of the motoring public. This mileage includes many different types, widths and thicknesses of bituminous surfaces constructed with and without special subgrade reinforcement or base courses. A substantial number of miles have been constructed primarily for experimental purposes to determine the suitability of different designs.

As a result of the knowledge gained from studying the experiences of other States (principally through the medium of papers presented at meetings similar to the Montana Bituminous Conference, from laboratory research, from experimental projects, and from the service record of all the bituminous surfaces constructed in the State since 1928, it has been possible to select, and more or less standardize, a few elements which are utilized in various combinations to make up the low-cost pavements which are now being constructed and will continue to be constructed in Nebraska. These elements of construction might be listed as follows:

(a) Stabilized soil base course.
(b) Prime coat.
(c) Bituminous stabilized base course.
(d) Dense-graded bituminous mat.
(e) Bituminous sand surfacing.
(f) Armor coat or seal coat.

Each project consists of one or more of these elements. The selection of a combination for a particular project is made after consideration of the factors of economy, type of soil, rainfall and other climatic conditions, amount and character of traffic, and the relative suitability of available aggregate materials.

STABILIZED SOIL BASE COURSE

A stabilized soil base course, as constructed in Nebraska, consists of a combination of natural soil and graded aggregates properly proportioned to produce an artificially graded mixture of clay, silt, sand, and gravel which is wetted, laid, and compacted on a previously prepared subgrade. The graduation of the mixture is such that after compaction the resulting density is as high as possible, and the pore space, including the space occupied by the remaining moisture, is as low as possible.

The first step in determining the materials to be used to make up the artificially graded mixture is to make a field survey of available local materials close to the work. All deposits of sand, gravel, or other aggregate materials are sampled and the approximate quantity available is determined. Samples of natural soil which might be suitable to supply the "soil binder" portion of the mixture are taken and tested. In addition, the subgrade is carefully sampled and tested at intervals where changes in the soil types occur. In this preliminary work the soil maps of the U. S. Bureau of Chemistry and Soils have been found helpful. From the results of tests of the preliminary samples, the type of mixture to be used is determined and the computations of the proportioning are made.

Two types of stabilized soil mixtures, (a) gravel type and (b) sand type, are included in the Nebraska specifications. The gradation limits specified are as follows:

	GRAVEL TYPE		SAND TYPE	
	Min.	Max.	Min.	Max.
Total per cent retained on the—				
1-inch sieve	0	5	....	....
¾-inch sieve	0	10	....	....
No. 10 sieve	30	60	....	....
No. 40 sieve	60	80	30	....
No. 200 sieve	70	85	65	....
Total per cent silt and clay	10	25	15	30

In addition to the above, it is required that the per cent of silt and clay shall not be more than one-half of the fraction passing the No. 40 sieve, and that the plasticity index of the material passing the No. 40 sieve shall be less than ten.

The gravel type of stabilized soil mixture is used extensively, and the sand type has been used on one experimental project. In designing the gravel type for a particular project, the available materials are combined in proper proportions so that the mixture will have 65 per cent retained on the No. 40 sieve, 18 per cent passing the No. 200 sieve and conform to the other requirements given above. It has been found that for most materials encountered in Nebraska that careful control of the gradation on the No. 40 and No. 200 sieves close to the values given provides a highly satisfactory and economical mixture. Coarse gravel and stone are extremely scarce in Nebraska but an abundance of fine gravel is available. Therefore, in most cases, it is not economical to attempt to obtain more than a 45 per cent retent on the No. 10 sieve. Uniformly good results have been obtained with gradations having only 35 to 45 per cent coarser than the No. 10 sieve.

In some instances it is desirable to adjust the per cent passing the No. 200 sieve according to the characteristics of the soil binder used. In general, the per cent passing the No. 200 sieve should be reduced to as low as 15 per cent for a soil binder having a relatively high liquid limit and high plasticity index, and can be safely increased up to 22 or 23 per cent for a binder relatively low in plasticity. If, in addition to the requirements given above, an additional condition is imposed limiting the liquid limit of the material passing the No. 40 sieve in the final mixture to not more than 25, most of the danger of getting too much binder of high plasticity and high shrinkage will be eliminated. In a locality where only soils of high plasticity can be found, it is believed that it would be desirable to give consideration to the use of soluble salts which through base exchange with the clay would change its properties by reducing its plasticity and shrinkage.

It appears that satisfactory results will be obtained when the compacted mixture is such that (a) water is not transmitted into it by capillarity, (b) the coarser particles of sand and gravel are in intimate contact with each other at as many points as possible and (c) the quantity and quality of the clay is such that the movement of grain on grain is prevented to as great an extent as possible, by the cohesion and adhesion of the clay and moisture films in the compacted mixture. The limits of gradation and plastic properties of the artificially graded soil mixtures enumerated in the foregoing paragraphs are the values which have been found to produce a mixture meeting these fundamental conditions.

PRIME COAT

A prime coat is used on all bituminous construction except bituminous sand surfaces. Type MC-1 asphaltic oil has been used on most of the work, although some tar has also been used. In either case, the quantity applied is ⅓ of a gallon per square yard.

A prime coat is considered desirable for several reasons. It prevents ravelling of the prepared subgrade or base course, as the case may be, during the construction of the surface course or in the interval between construction of the base and construction of the surface course. The construction of the surface course is aided by the priming of the base course, inasmuch as it partially waterproofs the top of the base. The prime also provides a surface free from loose material on which to mix the bituminous surface course and operates to make possible closer control of the aggregate gradation in the surface course mixture. Finally, the bond between a primed base and a bituminous surface course is much greater than if the base is not primed. This is quite essential to resist ''shoving'' where a relatively thin mat is to be constructed.

BITUMINOUS STABILIZED BASE

The construction of bases for subsequent surface treatment in which the soil is stabilized by the addition of a relatively small quantity of asphaltic oil has been attempted on a few projects in Nebraska. In each instance the subgrade soil was peculiarly suited to this type of treatment, being either a sandy loam or a very fine silty material with little cohesiveness. Where these conditions are encountered, clay is not available for the construction of a stabilized soil base course.

The procedure consists of scarifying the subgrade soil, pulverizing it, adding sufficient granular material to reduce the per cent passing the No. 200 sieve to about 20, and mixing from 4 to 5 per cent of MC-2 asphaltic oil with the resulting soil-sand combination. As soon as the materials are uniformly mixed, it is laid and compacted. On this type of work it has been found advantageous to have some moisture present in the soil mixture at the time the oil is applied. However, it is quite essential that this moisture be removed before laying and compacting.

DENSE-GRADED BITUMINOUS MAT

The most economical way to construct a dense-graded bituminous mat surface course is to use local materials to the greatest advantage, for the mineral aggregate. If widespread standardization of the requirements for the aggregates is attempted, even within the limits of one State, it is quite likely to prevent their use in many instances and as a result, substantially increase the cost of this type of construction. On the other hand, experience and research dictates some limits beyond which it is not safe to go if successful results are to be obtained.

In an attempt to write a specification which would insure mixtures which would give the best possible results and at the same time utilize available local aggregate materials, the following four standard gradations of combined aggregates have been established:

	GRADATION							
	A		B		C		D	
	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.
Total per cent retained on the—								
¾ inch sieve	....	5	....	5	....	5	....	5
⅜ inch sieve	....	35	....	....	....	....	....	....
No. 4 sieve	20	50	....	....	....	....	....	....
No. 10 sieve	45	65	30	60	....	....	....	....
No. 20 sieve	55	75	45	65	....	....	....	....
No. 50 sieve	70	85	60	80	40	....	....	40
No. 100 sieve	75	100	70	90	54	....	25	....
Total per cent passing the No. 200 sieve—								
(MC) Asphaltic Oils	4	8	7	15	12	24	10	30
(RC) Asphaltic Oils	2	6	5	10	9	18	4	12
Asphalt Emulsion	....	6	....	6	....	8	....	8

The limits given are master ranges of tolerance to govern mixtures made from any raw materials meeting specification requirements. A close control appropriate to the job materials is required for each specific project.

The gradation used most extensively is gradation "B." This is for the reason that the principal part of the total mixture can be obtained from an almost inexhaustible supply of sand and fine gravel in the Platte river valley which runs entirely through Nebraska from east to west, and from many other less extensive sources throughout the State. The fineness of this material as compared to crushed rock and the fact that it consists entirely of smooth, rounded particles makes the use of a rather high quality of mineral filler necessary, and requires close control of the proportioning and grading of all constituents of the mixtures.

Further assurance of the use of local materials is provided by designating on the plans certain pits from which the finer portions of the grading, i. e., fine sand and mineral filler, must be used. These materials are located by making a preliminary survey of all the available sources in the vicinity of each project and obtaining samples from them before the job is designed. Calculations of the proportions of various available materials are then made, based on the results of tests of the preliminary samples obtained. The most economical mixture for each individual project is then determined and the plans are prepared on this basis.

In designing each mixture the aim is to provide a combined aggregate conforming as closely as possible to a so-called "ideal" gradation which has been developed through research and which experience has proven to be satisfactory. For example, a combined aggregate within the limits of the "B" gradation which is to be mixed with an MC oil is designed to have between 70 and 75 per cent retained on the No. 50 sieve, between 80 and 83 per cent retained on the No. 100 sieve and about 11 per cent passing the No. 200 sieve. Careful attention given to providing a gradation having the proper percentage between the No. 100 and No. 200 sieves is quite as assential as providing the proper percentage finer than the No. 200 sieve and for Nebraska materials has much influence upon the stability of the bituminous mixture. The "ideal" gradation for each of the specified mixtures is very nearly the average of the maximum and minimum limits of gradation on each sieve as given in the above table.

The theory back of this specification which provides gradation limits that differ according to the maximum size of the aggregate in each case, and according to the type of asphaltic binder to be used, is based on the fact that the stability of a dense-graded bituminous mixture varies with the following factors:

(1) Maximum size of aggregate.
(2) Uniformity of gradation.
(3) Filler-bitumen ratio of the mixture.
(4) The consistency of the asphaltic binder in the mixture at the time of laying.

The maximum size of aggregate decreases successively for each gradation from "A" to "D", and to compensate for loss of stability on this account, the quantity of filler (material passing the No. 200 sieve) increases correspondingly. Similarly the quantity of filler specified is greatest for the softest asphaltic material and least for the hardest asphaltic material. Also, if greater stability is desired for some particular reason on a specific project, it is obtained either by increasing the quantity of filler or by using an aggregate with a large maximum size. In other cases, the stability is controlled by the extent to which the bituminous mixture is aerated when cut-back oils are used, which is simply controlling the consistency of the asphaltic binder in the mixture at the time of laying.

For the determination of the quantity of bitumen required in each mixture the following formulas have been used successfully:

For gradation A and B—

$$P = AG\,(.02a) + .06b + .1c + Sd$$

For gradations C and D—

$$P = AG\,(.02a) + .04b + .06c + Sd$$

where

P = per cent by weight of bitumen required in the bituminous mixture prior to laying.

a = per cent by weight of aggregate retained on the No. 50 sieve.

b = per cent by weight of aggregate passing the No. 50 sieve and retained on the No. 100 sieve.

c = per cent by weight of the aggregate passing the No. 100 sieve and retained on the No. 200 sieve.

d = per cent by weight of effective filler material in the combined aggregate (arithmetic average of the results obtained by the wash test and by dry sieving).

S = a factor depending upon the fineness and absorptiveness of the effective filler material.

A = an absorption factor for the aggregate, which in the case of Platte River gravel is equal to unity, and is determined for other aggregates for each individual job. (The factor should be applied to only the portion of the combined aggregate that is absorptive.)

G = specific gravity factor which is computed by dividing the bulk specific gravity of the aggregate being used into 2.62 (bulk specific gravity of Platte River gravel).

These formulas are similar to several others in common use except for the factor "S". The significance and determination of this factor has been explained at a previous Montana Bituminous Conference.*

The per cent of cut-back oil to be added is then computed by the following formula:

$$N = \frac{100\,P}{100-P}\,K$$

where

N = per cent by weight of cut-back to be added based on weight of aggregate.

P = per cent by weight of bitumen required in the bituminous mixture.

K = a factor to compensate for loss of volatile portions of cut-back by aeration.

For MC oils K = 1.1 when total distillate to 680° F. is 15-20%.

K = 1.15 when total distillate to 680° F. is 20-25%.

For RC oils K = 1.15 when total distillate to 680° F. is 15-20%.

K = 1.2 when total distillate to 680° F. is 20-25%.

The per cent of emulsion to be used is computed in a similar manner, proper account being taken of the quantity of water in the emulsion.

Aeration of the bituminous mixture or the process of removing a substantial portion of the volatile materials in a cut-back oil after the mixing process is completed has already been mentioned as a means of controlling the consistency of the asphaltic binder. Proper aeration is considered absolutely essential to successful use of cut-back oils with Nebraska materials. Unsatisfactory surfaces have resulted in almost every case where it is known that the mixture was not aerated sufficiently.

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*"Sand Surface" by F. S. Gilmore, Highway Engineer, The Asphalt Institute, Proceedings of the 1935 Montana Bituminous Conference on Modern Bituminous Practice, page 97.

BITUMINOUS SAND SURFACING

In the sand-hill region of Nebraska, which is a fan-shaped area located in the north central portion of the State comprising about one-fourth of its area, the stabilization of the natural sand with asphalt to provide bituminous sand surfaces has been quite successful. This work has already been presented in detail at one of these meetings and will not be repeated here.* Instead, a few conclusions that have been reached from the experience with these surfaces are presented.

(1) In order to properly stabilize sandy soils with asphalt, it is necessary to use the same care in the selection of fillers or aggregate admixtures and in the proportioning of materials as is used in the design of dense-graded bituminous mat mixtures.

(2) When bituminous sand surfaces are constructed directly upon dune sand subgrades, it is necessary to provide 5 to 6 inches of stabilized sand having a stability value** of from 300 to 400 pounds at 77° F. in order to distribute wheel loads over a sufficient area of the sand subgrade to prevent its displacement.

(3) When this type of surface is constructed on sandy loam with 20 to 30 per cent finer than the 200 mesh sieve, a thickness of 3 to 4 inches is required having a stability value of from 600 to 700 pounds at 77° F. in order to properly carry the loads imposed on it.

(4) It is more economical in most cases to rectify the gradation of the soil rather than attempt to use special asphaltic materials or to use a high percentage of oil in the mixture.

(5) The percentage and type of filler material in the mixture is the chief influence on the stability of the mixture and is the principal factor affecting the quantity of oil required.

(6) The use of MC oils permits a greater variation in the mixture without endangering satisfactory results than does the use of SC oils because of the higher stability and cementitiousness provided by the MC materials. These qualities permit the use of inferior gradations and higher oil percentages when necessary than is possible with SC materials.

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*"Sand Surface" by F. S. Gilmor, Highway Engineer. The Asphalt Institute, Proceedings of the 1935 Montana Bituminous Conference on Modern Bituminous Practice.

**Nebraska modification of Hubbard-Field stability test using 2-inch by 1-inch briquette.

ARMOR OR SEAL COAT

According to Nebraska practice, an armor coat consists of the application of a coat of bituminous material on a previously prepared base or existing surface and a covering of gravel or other aggregate. Type RC-2 asphaltic oil is usually used for this work. It is applied at the rate of one-fourth gallon per square yard and covered with 25 pounds of fine gravel per square yard. An armor coat is applied on all bituminous mats the next season after the mat is constructed and is included as part of the surface course. It is the practice to keep the bitumen content of the bituminous mats a little to the lean side and to prevent excessive ravelling by the use of an armor coat rather than to go to a richer mat mixture.

SELECTION OF COMBINATIONS OF ELEMENTS

As has already been stated, the selection of the proper combination of the elements enumerated for a particular job depends upon several things. In some instances the proper combination is fairly obvious, while in others it is necessary to make detailed studies of the pertinent factors affecting the selection before a decision can be made.

In the sandhill region of Nebraska the 5 or 6-inch bituminous sand surface is used where the subgrade is dune sand and a 3 to 4-inch thickness is used where the subgrade is a sandy loam. A prime coat is not used with this type of construction. A 3-inch bituminous sand mat meeting the specified requirements of the ''D'' gradation of the dense-graded mixtures is sometimes constructed on a sand-clay base which has been previously used as a surface on a dune sand subgrade. The sand-clay base is always primed when this type of construction is employed.

The soil in some localities in Nebraska consists of a well proportioned natural mixture of sand, silt and clay and when the subgrade consists of such a material in a region where the average annual rainfall is comparatively low, with topography such that good surface drainage can be obtained, a dense-graded bituminous mat is used and constructed directly upon the subgrade. A prime coat is applied to the surface before the mat is constructed. The mat is constructed 2 inches in thickness and 24 feet wide. An armor coat is applied the next season after the mat is completed.

Where the soil is light, consisting of fine sand and silt, and where clay is scarce, bituminous stabilized bases are employed. They are constructed 3 inches in thickness and 24 feet wide. It has been the practice to prime the subgrade but because of the light character of the soil, it is difficult to keep the prime coat intact while the base is being constructed. An armor coat is provided as a wearing course on projects of this kind.

Stabilized soil base courses are constructed in all localities where the soil contains a substantial amount of clay and is lacking in coarser materials. Where the rainfall is low and the soil is low in plasticity a base course 2 inches thick is used. In other places the standard thickness is 3 inches and this is increased to as much as 8 inches in special cases where surface drainage is poor, rainfall is heavy, or the subgrade consists of an inferior type of soil. In all cases the base is constructed to a standard width of 27 feet.

Bases 2 inches or 3 inches thick are constructed on top of the existing road and are not ''trenched'' into the roadbed. When bases of greater thickness are constructed, the shoulders are built up to within 3 inches of the elevation of the edge of the base. This practice insures rapid runoff of surface water at the edges of the base and is an important factor in keeping the subgrade under the edges from becoming soft and unstable, thereby preventing edge failures of the base. Objections to it have been raised from the standpoint of safety but it is believed that where the base is constructed to a width of 27 feet the ''step-off'' at the edge does not constitute a traffic hazard. A roof-shaped crown is used sloping uniformly from the center at the rate of ¼ of an inch per foot. This is considered to be the minimum crown that should be used.

The base course is always primed before the surface course is constructed upon it. The surface course may be either of two types—a 2-inch dense-graded bituminous mat, or a double armor coat treatment. In general, the determination as to which type should be used on a particular job is based upon the amount and character of traffic and the character of the subgrade soil. On heavy traffic roads, in localities where it is expected that the surface might be subjected to considerable abrasion from tire chains in winter or at times when side roads are muddy, and on projects where it is considered necessary because of the character of the soil to provide greater total thickness of base and surface course in order to distribute wheel loads over a large area of the subgrade, the two-inch bituminous mat is used. Where these conditions are not so adverse, the double armor coat treatment is used. The use of a combination of armor coat and stabilized soil base course has been entirely satisfactory, in fact so satisfactory that future plans will call for a more extensive use of this type of surface.

THICKNESS OF BITUMINOUS SURFACES

The total pavement thickness of various types of bituminous surfaces used in Nebraska are as follows:

Bituminous sand on dune sand subgrade	5″ or 6″
Bituminous sand on loamy sand	4″
Bituminous sand mat	3″
Bituminous mat (2″) and Stabilized base (2″)	4″
Bituminous mat (2″) and Stabilized base (3″)	5″
Bituminous mat	2″
Stabilized soil base and double armor coat	3½″

The thickness of bituminous sand surfaces which is necessary to prevent displacement of the subgrade material under wheel loads has been determined by observation of the performances of such surfaces constructed of different thicknesses. Dune sand is cohesionless and is low in internal friction. Four-inch bituminous sand surfaces have shown failures due to displacement of the sand under the pavement whereas surfaces 5 or 6 inches thick have been consistently satisfactory. The effect of increasing the thickness of the surface, upon the bearing power of this kind of subgrade is twofold. The thicker surface distributes the wheel load over a large area of the subgrade and increases the surcharge on the portion of the subgrade outside the limits of the loaded area. This surcharge, or weight applied adjacent to the loaded area, has a significant effect upon the load which a subgrade of cohesionless material will support,* and the increase in subgrade bearing capacity resulting from an increase in the surcharge undoubtedly contributes substantially to the successful performance of a 5-inch bituminous sand surface as contrasted with the unsuccessful performance of the 4-inch surface on subgrades consisting of dune sand.

Dune sand mixed with 10 to 20 per cent of silt loam produces a subgrade with much greater internal friction than pure dune sand and has correspondingly higher supporting power. On subgrades of this character, a 4-inch bituminous sand surface has been found to be satisfactory.

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*See Page 53, "Public Roads," May, 1929. Interrelationship of Load, Road and Subgrade by C. A. Hogentogler and Charles Terzaghi.

Bituminous sand mats are constructed 3 inches in thickness on stable sand clay subgrades. It is believed that this thickness is necessary to resist the shearing stresses produced by moving vehicles. Bituminous sand mixtures are more permeable than the coarse graded mixtures, and therefore, the 3-inch thickness is considered desirable to prevent the passage of water through the surface into the subgrade.

The combinations of bituminous mat and double armor coat with 2-inch or 3-inch stabilized soil base courses form semi-rigid pavements 3½, 4, or 5 inches in thickness. The successful performance of these surfaces on silt and clay subgrades indicates that the semi-rigid pavement has advantages which are not fully appreciated, and that developments in rational methods of design and in the use of proper materials offer great possibilities for improved pavements and for economies in their construction and maintenance.

The formula developed by Bernard E. Gray** for determining the required thickness of a flexible pavement is as follows:

$$t = .564\sqrt{\frac{W}{S}} - e$$

where

t = thickness of pavement in inches
W = unit wheel load in pounds
S = subgrade resistance in pounds per square inch
e = radius of area of tire contact in inches

In the development of this formula it is assumed that the load distributes itself throughout the pavement in a conoidal fashion and that the sides of the cone of distribution intersect the subgrade at an angle of 45°. If this angle is denoted as θ this formula becomes

$$t = \left[.564\sqrt{\frac{W}{S}} - e\right] \tan \phi$$

It is reasonable to expect that if the load is distributed throughout the pavement in the manner assumed, the sides of the cone of distribution will intersect the subgrade at a more

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**From The Design and Construction of Bituminous Pavements by Bernard E. Gray.

acute angle in the case of a semi-rigid pavement than in the case of a flexible pavement because of the higher shearing strength of the semi-rigid type. This would decrease the required thickness of the semi-rigid type by the ratio obtained by dividing the tangent of the angle θ for this type by the tangent of the angle θ for the flexible type.

One of the most widely accepted methods of computing the stresses in a rigid pavement is the one proposed by H. M. Westergard.* The formula developed for computing stresses due to wheel loads contains a significant term which is called the modulus of subgrade reaction which is expressed in pounds per square inch per inch of deflection. If the subgrade is compressed under the pavement by deflection of the surface caused by a wheel load, the modulus of subgrade reaction increases and more of the load is supported directly by the subgrade and loss by the flexural strength of the pavement. The deflection of a concrete slab without rupturing is small as compared to that of a semi-rigid pavement and therefore it appears that the rigid type cannot have the advantage of increased support resulting from compression of the subgrade soil, to the extent that the semi-rigid type can, unless it is broken into relatively short slabs.

It appears from a consideration of these factors that the semi-rigid pavement has the advantage of the subgrade support given the flexible type and in addition the property of the rigid type of extending the area over which wheel loads are distributed on the subgrade. As a result, the possibilities of the semi-rigid type appear to be greater than those of the other types. From highly satisfactory results obtained in Nebraska with stabilized soil base courses and from these theoretical considerations, it seems justifiable to construct bases only 2 or 3 inches in thickness, and to look to the use of stabilized bases with armor coat treatments as being the best possibility for economy in pavement construction.

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*Stresses in Concrete Pavements Computed by Theoretical Analysis, Public Roads, April, 1926.

Developments in the Fundamentals of Bituminous Construction

By

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Webster defining fundamentals as pertaining to the ''foundation or basis'' of a thing, we will attack the subject assigned from that angle. Believing that it is desirable to bring forth as much profitable discussion as possible, we will also diverge from a strict interpretation of the subject whenever it is felt that anything of value might be brought to light.

While claiming no especial knowledge of the subject that is not available to any engineer active in the Highway Construction Field, we feel that we are all seeking a uniform practice and design, subject to the variations of temperature range, annual precipitation and types of soil and are all willing to devote considerable study to an intelligent solution of the problems to which all States of large areas, small population and limited budgets are subject. This small population, which is generally very familiar with the personnel of a small organization and derive a considerable portion of their incomes from the tourist business, is very critical of road conditions and does not hesitate to bring to the attention of the officials responsible conditions that might reflect on their pocketbooks, as there is a tendency among the general public, both local and out of state, to compare our low cost roads with the rigid type pavements of the more populous east.

We have often thought that responsibility for a smooth operating highway system should be more or less equally divided between at least three bodies. The first is the travelling public: no Highway Department will be much better than is required of them by this body. The second is the vehicle manufacturer, who has sensed and surely feels some responsibility for the construction of relatively cheap, economical and safe vehicles. The third, and most active agency, is the Highway Department, more or less caught between the other two and definitely committed to a policy of trying to satisfy both. A sort of vicious circle is formed.

Every few years the public demands and usually gets a faster, more economical vehicle and promptly wants a wider, safer road with all weather surfacing to run it on, with consequent increased construction costs. The raising of design standards the past ten years has been of almost yearly occurrance in all organizations. The cost level has risen more slowly due to more efficient methods brought about by a better understanding of the problems involved, by both engineer and contractor, and the improvements in methods and machines. Generally speaking, unit prices are lower for the same items than in 1927. About that time our roads were being constructed for a speed of 35 miles per hour and the all-weather road with year around maintenance was beginning to be seriously considered. The public was just beginning to become educated in the vagaries of installment purchasing, which put the low priced car within reach of the average citizen, and after buying it he wanted to use it whenever he chose. Up to this time the roadbeds were poorly drained and a few inches of crushed gravel was thought to be the ultimate in road surfaces for this country. As vehicular traffic increased, both in amount and speed, there was a kick back in that these surfaces were usually rough and dusty, and maintenance costs began to rise due to a dry, arid climate, subject to high winds of long duration. Further the loss of material from this traffic and winds began to assume serious proportions and it was recognized that Wyoming would soon be out of business as a construction organization unless some type of cheap, smooth pavement could be designed that would be satisfactory from all angles. Various oil companies and west coast states had attacked this problem several years previously and had devised a system of using road oils to bind the aggregates together that seemed satisfactory at the time. There was very little information available on types or grading of materials, how to arrive at a suitable amount of oil necessary to bind any particular type or grading of aggregate.

Construction methods and the probable maintenance costs and methods were only wild guesses as far as Wyoming was concerned. Using the experience of those few states that had constructed cheap road oil mats, as far as it was applicable, as a starting point, it was then necessary to devise designs and construction methods and train both construction and maintenance forces in the use and repair of the new material. The only phase of the whole layout that was easy to find out was whether or not the public was willing to pay for oiled roads. After two or three short experimental sections were built and used a year there was such a demand for oiled roads that to date the Department has been unable to altogether satisfy the citizens of this State with respect to total mileage built. The first and only thought responsible for the building of our oil mats was to reduce loss of material, reduce maintenance costs, and provide a smooth, dustless road surface. For several years all the mat possible to finance was placed on old gravel roads, carrying the heaviest traffic and usually located near the larger towns or oil fields. With the constantly increasing amount of through traffic it later became necessary to consider routes rather than localized sections and such is still the case. As there was no specialized equipment, no cost data, no contractor with any training or experience along these lines, no engineers available with any but the most rudimentary knowledge of what it was all about, the first three seasons' work was done with at first two and later three force account crews.

Admittedly the first jobs were pure experiments, mistakes were made and failures resulted. Much stress was laid on getting an oil mat and no particular attention was given the quality or thickness of the base gravel or the soil type of the subgrade. This was the natural result of changing 1500 miles of important highway from a gravel standard to an oil standard in such a short period of time, and with the knowledge then at hand. Only road oil was readily available, as few refineries were properly equipped to make cutbacks within our financial means (when results were to be unknown) and this oil of the old 60 grade type. It was of mediocre quality and did not contain enough asphalt to properly function as a binding agent.

For the three years from 1927 to 1930 practically every effort was along construction lines and on projects that had old gravel surfacing. During this period much experience was gained, men were trained, equipment developed, cost data gathered and with the aid of the oil companies, various grades of road oils and cutbacks were developed, and the new and more exact methods of using them were determined. Further, contractors had watched these force account crews and with the personnel trained and equipment developed were willing to bid and do this type of work.

About 1930 when some few oil mats were three years old, and maintenance methods and comparisons between projects could be made, the cost analysis showed startling difference in maintenance cost on projects of approximately the same length and with about the same mat materials and road oils. It was thus brought forcibly to our attention that there were other items entering the equation than just oiling some gravel or crushed rock and laying it down in a smooth mat. It was found that the failures and high maintenance cost were mostly on old roads, with poorly designed drainage and bad soils such as the gumbos. Specifications were immediately revised to compel drainage of all borrow pits, cuts were designed with longer hauls, augmented with the development of machinery that could make a long haul cheaply; fills were constructed in one foot and later 8 inch layers to secure better compactions, with consequent less settlement and various types of base course gravels with varying thickness were used.

With more attention paid to drainage and sub-grade construction, the roads built from 1930 to 1934 have shown a much lower maintenance cost, although we were still having some trouble in the poorer soils from sub-grade failure in the outer thirds of the roadway or spots of very poor soil.

The 1935 roadbeds were widened from 26 to 36 feet on the heaviest travelled routes and from 26 to 30 feet on all others. Further, comprehensive soil surveys were made on all locations of a questionable nature and either pit run gravel or crushed gravel was used to make a base thickness which experience has indicated would be strong enough to carry the probable amount and kind of traffic.

The roadbeds had been covered with from three to six inches of crushed rock or gravel, with no binding agent added and with a small amount of annual rainfall were usually loose, washboarded and dusty. While more or less intangible it is known that this type of surfacing affects the operation of motor vehicles to a considerable extent. Further, three years maintenance had shown that this type base was structurally weak in the outer thirds of its width, particularly due to the ease of water entering and softening the shoulders and partially from maintenance methods, with blade graders, which pulled the loose gravel into the center of the roadbed, where it was least needed, to level up the section caused by traffic compaction. Further, when the oil mat was placed, the loose base material was picked up and incorporated in the mat, thus increasing its thickness over the theoretical section and also weakening the base. Several variations of this section were tried but no particular scheme proved to be of any great value until in the summer of 1933 several thickened edge oil mats were constructed. These were about 2½ inches in the middle and thickened to about 4 inches in the last two feet next to the shoulder. These mats quickly proved their superiority as far as mats were concerned, but were weak in design in that the trench for the thickened edge was cut through the base gravel and collected moisture which contributed to failure of the mat.

Only a few of these jobs were constructed. A section was then designed, which is still in use, that has a high crown in the subgrade, a lesser amount of crown in the gravel or crushed rock base, which makes a thick base section on the outer thirds of the road bed. The standard thickness is 6-4½-6. Building this section by blade graders usually the true section is somewhat thicker at the edges and a little thinner in the middle than the theoretical. This section has proven to be very stable as total thicknesses are varied according to soil conditions. This system is still in use and runs from 2″ base on sand or sand-gravel subgrades to as much as 18″ on very poor gumbo. Fortunately, we have the extremely bad condition in only localized sections and the average base is usually around 5″ thick. Although we have only two years of this type in service, indications are that we have the base problem fairly well under control for existing traffic.

During this period from 1934 to 1937 we had thought that a binding agent, with more resistance to shearing action of vehicular traffic and to the action of water accumulated under the mat by capillary action, would be desirable and there has been a tendency to work to the cutbacks with higher asphaltic contents. This was a gradual process. In 1934 several projects mixed with MC 2 oils were tried. These are only fair and require heavy traffic to keep in good condition. Further, from 1% to 1½% more liquid is seemingly necessary, particularly in the thin mats, to thoroughly stabilize the material than if SC-3 is used. The latter part of this same season we went to MC-3 cutback with better results. This also requires about 1% to 1½% more material than SC-3 but makes a very stable mat. This practice is still standard on all the system but at present there is some study being directed towards going back to SC-3 on the lighter traffic roads with the A1, A2 and A3 soils. This reaction is largely due to first cost and the fact we have some old 60 grade projects, on good soils, that are 8 to 10 years old and have been maintained for a very nominal figure. The MC cutbacks have the further advantage of being very resistant to skidding action as the mix usually appears rather harsh but rides o. k.

There has been some doubt as to our ability to maintain the cutback mixes with one man units. However, it has proven to be, at least in some cases, easier to remix than SC-3. The SC-3 mats over three years old form a crust that can be scarified but is very difficult to break down to original size. The MC grades apparently do not form this same glazed surface and can be readily remixed.

Summarizing the past ten years, we have seen the gradual development of:

1. Stiffer mats by going from road oils to cutbacks.
2. More stable, easier controlled mixtures, due to better mixing equipment, methods and improvements in the refiners processes of making the liquid binder.
3. A better understanding of the importance of well built, drained and compacted subgrades.
4. A realization that the mat is a riding surface only and that its strength depends almost entirely on the base and subgrade.

Developments in the Fundamentals of Bituminous Construction

By

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The development in the Fundamentals of Bituminous Construction in Alabama can best be traced by reviewing the trend in construction.

Years ago when it was decided to place a bituminous surface, the project selected was always one that had a graded earth surface which had been thoroughly compacted and weathered for several years. This type of surfacing did not prove entirely satisfactory because of the lack of sufficient supporting power of the old graded earth surface and because the base course materials used would not withstand weathering and volume change after same had been sealed. However, one important fundamental principle was adhered to; that of using a thoroughly compacted and weathered base course under the proposed bituminous surface. As time went on and the demand for all weather roads became greater we found ourselves slipping from the above fundamental practice in order to speed up construction. Now we are debating what can be done to get our roads paved quickly and yet have thoroughly compacted and weathered road beds and base courses under our bituminous treatments.

Our present practice is not to disturb the old roadway wherever possible and place our graded earth base course in layers, wetting same and using artificial methods to assist traffic in the compaction of the several courses. This procedure appears to be satisfactory, except that we do not get the advantages of nature's weathering.

The next fundamental development has been in the improvement in the kind of graded earth materials used in the construction of the base course. It is our belief that the advancement made in soil analysis is such that we are reasonably sure of a good base course if we select materials which are well graded, have low volume change and good soil characteristics as determined by the tests now standardized for such work. Our pressing need in this field is to secure test methods and equipment which will indicate the behavior of the material under weathering and just how much support we can expect from them so that more of our local materials can be used in their natural state without admixtures.

In the matter of the bituminous surfaces we can report several developments. Our standard hot asphaltic mixtures laid in thickness of 2 inches to 6 inches are mostly all cracked, and we believe this trouble is due at least in part to fundamentals; the use of too dense a graded mix which cannot move as the changes occur in our flexible bases and to the use of low penetration asphalts which oxidize and lose their value for flexibility. We do not have this trouble in our medium dense graded plant mixes and road mixes which are laid between 1½ and 2 inches in thickness and are made with cut back asphalt or tar.

Our most used type of surfacing, that is the inverted penetration placed mostly on graded earth bases of local materials, has proven to be our best type because the fundamental principle of design of this type of construction appears to be the best one to fit our conditions and is proving the biggest step forward in road construction in our state. With good control of construction details and the use of properly selected local materials, we find first that a base course of 6 to 8 inch minimum thickness is satisfactory support for the surface course. This type of base course at present is satisfactory for our present type and volume of traffic. To complete this type of construction we place our one thickness of stone-inverted penetration type surface. This forms a weather-proof roof to protect the base course from an average of 50 inches of rainfall that we have yearly. It is a stable surface, because we use as nearly a one-size aggregate as it is practicable to produce, which forms a mat of uniform size, each particle touching the other so that no shoving results. The use of a straight high penetration asphalt or tar applied hot gives the weather proofing film next to the base course that cannot be had by any other method at anywhere near the same cost. Due to the type of aggregates found in this State and the fact that our bases are not unyielding we find that the average ¾ inch mat of inverted penetration is not always held in its original position and therefore to prevent the wear on the aggregate, if there be any, and to help prevent the aggregate from being pressed into the base course by traffic, we find it advisable and economical to place a ''void filling'' seal coat after the mat is thoroughly keyed. The largest benefit of the seal coat is to further interlock the aggregate particles with smaller sized pieces which at the same time helps to keep the weathering away from the hot application of bitumen. It also provides for traffic, a medium graded non-skid surface which does not wear so quickly.

Bituminous Mat Development in Kansas

By

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In the seven years since 1930, many miles of bituminous surfaced roads have been constructed in Kansas. Methods have varied considerably to meet demands for this type of construction with the funds and materials available. Due to persistent public demand for a large mileage of all-weather and dust-free roads, Kansas immediately started on an extensive program of Bituminous construction. On January 1, 1931, 26.6 miles of bituminous surfaces were maintained. This had increased to 1,638 miles by January 1, 1933, and 3,250 miles by January 1, 1937. Construction has varied from simple earth penetration treatments, mulch and very thin mats utilizing aggregate residues from sand-gravel maintenance, to heavy mats of carefully graded sand-gravel-fines and crushed limestone.

Original construction consisted of 1200 cubic yards of closely graded aggregates per mile using slow curing asphaltic oils as a binder. To meet the demand for greater mileage of bituminous construction, lighter type mats were evolved. Considerable mileage has been constructed with aggregate quantities of from 200 yards per mile on some early experimental construction, a considerable mileage using 575 yards per mile, and late construction 1200 to 1400 tons of aggregate per mile.

The most satisfactory mat to date has been secured from a closely graded aggregate containing an appreciable amount of material passing the 200 mesh sieve. The gradations approach closely a maximum density for the combined aggregates with a comparatively low void content for the mixed and compacted mat surface. A standard aggregate specification in use for several years is as follows:

Pass 1″	Retained ⅜	Retained 8	Retained 30 not more than	Pass 200
100%	15-30%	25-50%	75%	8-15%

In order to secure a more tractable surface, coarse material has been added to one specification and has given good service. This is as follows:

Pass 1½″	Retained ¾	Retained 4	Retained 30	Pass 200
100%	10-30%	30-50%	60-80%	5-10%

The asphaltic materials have varied from the predominate use of AO or slow curing oils during the years 1930 to 1933, to the present large percentage of MC type cut back asphaltic material. This type of material has advantages over the slow curing types of asphaltic materials, but recent research indicates some possible disadvantages of cutback material.

The paper presented at the 1936 Montana Conference mentioned the construction in progress at that time of coarsely graded aggregate bituminous mat. Approximately 120 miles of this type of mat was constructed in 1936. The gradation of the aggregates was as follows:

Retained 1½″	Retained ¾″	Retained 4
0-5%	20-60%	90-100%

This material was placed at the rate of 1200 tons per mile, using from 5% to 6% AC binder from MC 3 to MC 4 cutback asphalts. Approximately 200 tons of keystone was broomed and rolled into the coarse structure resulting, together with applications of from .2 to .4 gallons of cutback MC 3 or MC 4 per square yard of surface as a binder for the keystone.

A considerable portion of this type mat was laid on old existing mats and on old penetration, some of which were rather badly disintegrated before laying the new mat. Dirt shoulders were built up to the surface of the new mat. It was believed that the old bituminous construction would provide sufficient protection to the subgrades below to minimize the danger of water penetration into the subgrade from the comparative water permeable mat above.

This type proved far more permeable to water than had been expected. The built-up shoulders proved very detrimental soon after construction. Fall rains and snow which began soon after completion of the mats, passed quite freely through the mats to the old surfaces, where drainage was prevented by the shoulder construction, forming a saturated pool of water above the old base. This retention of water over the old construction quickly led to its breakdown, with seepage of considerable quantities of water into the subgrades below. Due to the lateness of the season, it was impossible to correct these conditions as they became apparent.

The absorption of water by the subgrades and the freezing and thawing on the water held in the mats led to the destruction of a large percentage of this type of construction in the spring of 1937. Several projects where the old mats and base were in good condition and where sub-base construction was performed, withstood the winter without extensive failure, and have now been tightly sealed. These mats will apparently give satisfactory service, although they constitute only a small portion of the open type 1936 construction.

Due to the difficulties encountered with this type of construction, no new construction of this type is contemplated.

The coarse aggregate or open type mats which failed in the spring of 1937 are being salvaged by several methods. Several projects have gradations which will permit their conversion into dense type mats with the addition of only a small amount of fine aggregates. Portions of these mats are being scarified, the gradations brought up to dense mat requirements by addition of suitable material, more asphaltic material added, after which the composite materials are mixed and relaid as dense type mats.

Other projects where this procedure would involve too great an expense, are being scarified to several inches below the original construction after which the scarified material is bladed, mixed and then compacted with sheeps-foot rollers. This surface will then be penetrated and a cover stone armor coat applied. It is believed that this procedure will form a satisfactory road surface and will further serve as an excellent base for future construction.

Subgrade stabilization and sub-base construction has been used to some extent in Kansas bituminous construction. Stabilization of small areas of silt and loam soils have been accomplished with the use of Portland cement. Clay has been used for a number of years in the western sections of the state as a topping over blow-sands, the topping usually being from 6″ to 12″ in thickness. Clay has been intimately mixed with unstable sands and sand with unstable clays to produce stabilization with good results. It is interesting to note that some sections having a clay topping and serving as a base for bituminous construction have had considerable more maintenance than adjacent areas over the sand subgrade due to absorption of moisture from the shoulders, causing a softening and failure of the clay and the mat above. The clay topping in each case had been in use as a sand-gravel surface previous to placing the bituminous surfaces.

Considerable base construction was placed under the open mat construction of 1936. The bases were placed at points of ground water interception, and have indicated their value by reducing failures at these points. These bases were constructed of sledged or crushed stone and formed bases of from 5″ to 6' thick. Several miles of salt (NaC1) stabilized base was constructed in 1936. The salt was added as an admixture at the rate of two pounds of salt per square yard of surface, with .8 pounds per square yard on the subgrade. Aggregate was added and the aggregate-soil-binder mixture wetted, mixed and compacted. The resulting base was from two to four inches in thickness. This base has given fair service except for several edge failures in which a large lateral displacement of the subgrade has occurred, caused by water absorption from the shoulders. This source of water is apparently the cause of much trouble, even though stabilization and base construction have been utilized.

Soil Surveys As Related to Base Design For Bituminous Surfacing

By

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The two principal types of surveys made by Soils Engineers in Minnesota for use in designing aggregate bases for bituminous surfacing are: Soil surveys and condition surveys.

Soil surveys are made both on existing roads and on new locations and are of two general types:

1. Surveys of localized areas of frost boils, frost heaves, seepage, slides, etc.
2. General mapping soil surveys which are used primarily to obtain knowledge of the soil types. This information may later be used as a basis for selection of materials during grading operations and for determining the depth of base required.

Condition surveys are made twice a year on existing roads where further construction is contemplated. The first survey is made in late winter when frost penetration has reached its maximum, and the second in the spring during the period of break-up when moisture conditions and subgrade weaknesses are at their worst.

The first condition survey in the winter has as its primary purpose the location and measurement of frost heaves. These are so tied into stationing or topography that they are easily located later in the year when more detailed investigations are made. The second condition survey during the period of the spring break-up is for the purpose of locating frost boils and other areas of subgrade weakness. These also are tied into stationing or topography so that they can be located when more detailed information is desired.

At the time of the spring condition survey, the general condition is also observed as this may influence the design of base in considerable degree.

These condition surveys are available on numerous roads in Minnesota for four or five years before additional construction is accomplished and have proved valuable in elimination of frost heaves and frost boils.

In the design of bituminous roads, these subgrade defects must be eliminated in order that the smoothness of the finished surface may not be spoiled by short areas.

After the sections as noted above are definitely located, a detailed soil survey is made on the localized areas in an attempt to determine the cause of the defects. It has been shown by our experience in Minnesota that successful elimination of these defects can be accomplished only when the cause is definitely known. To this end, detailed borings are taken in the defective areas which were located during the condition surveys.

The localized defective areas most commonly encountered are caused by frost heaves, frost boils, roadside springs, seepage areas, and slides. In addition to these there are also areas having slight subgrade weaknesses on which no definite failure has been noted but which may fail under more severe traffic or weather conditions. The treatments of these various defects, vary according to the conditions as found in the detailed soil survey. In general, we may say that frost heaves are corrected by excavation and backfill; the frost boils by excavation or lift or a combination of the two. The damage caused by springs may be corrected by tiling or by excavation and tiling. Tiling and intercepting trenches are also used where seepage planes occur within depths of ten feet below the road surface.

The solution or correction of slides is often very difficult, especially in determining the cause. Once this is definitely determined, the correction is usually possible through either replacing of slipping material with soil material of higher internal friction or by eliminating the source of water which provides the lubricated plane on which the slide occurs.

After the location and cause of these localized defective areas has been ascertained, the general soil survey is made. The procedure is much the same whether or not the proposed construction is on an existing road or on a new location.

Information obtained from condition surveys and general soil surveys is utilized in the design and construction of grading projects in several ways, the principal objective being to grade the road in such a manner as to keep required thickness of base and expensive surface to a minimum.

On a job which will be graded or re-graded prior to the base and surface construction, the soils are mapped according to their texture, particular attention being paid to the different soil horizons and the characteristics of each. We endeavor to control the grade line of the proposed road so to cause it to lie in the most stable soil and thus reduce the thickness of the base required to support the bituminous surface. In a lesser degree it may also be possible to effect slight changes in alignment to avoid areas of particularly bad subgrade conditions. If it is not practicable to avoid areas of unstable subgrade soils by changes in grade line or alignment, the design may provide for subcutting of such areas and for backfilling with the more stable soils which have been located by the Soils Engineer.

On a new location where information from condition surveys is not available, the Soils Engineer, by means of boring, locates those areas where subgrade weaknesses will probably develop. Corrective measures are then included in the construction plans. In deep cuts where it is difficult to obtain detailed information by boring prior to grading, a check is made during the grading operations. Areas of low stability or probable heaves or boils may be inexpensively eliminated at that time.

Soils Engineers may make special surveys to locate borrow pits containing soils which are relatively more stable than the soils encountered in a normal roadway excavation. It has proved economical in some cases to construct the upper portion of the road-bed from borrow material or better quality than that of the subgrade soils. On one project so constructed, the depth of gravel base deemed necessary was decreased from approximately 8″ to 4″ by the use of selected borrow material in the grading operations.

In some instances, when portions of the proposed project lie in gravelly or sandy soils, an attempt has been made to use this material over the top of the grade throughout the project. This may be done by including the sand or gravel material in the earth-work quantities, in which case the only additional cost involved will be that of the extra haul on the materials. In this way a base for bituminous surface may be constructed during grading operations at very little additional expense.

It has lately become the practice to require rolling of the new grade with a sheepsfoot roller to obtain compaction prior to the placing of bases. This compaction has proved valuable where an attempt is made to control the type of soils placed in the upper foot or two of the roadbed. The soil should be near or at the optimum moisture content when it is consolidated. As an example of this construction, a mile of road was graded, using a foot of selected top soil on the fills and two feet of selected top soils through the cuts. The topsoil was rolled in comparatively shallow layers by a sheepsfoot roller. This section of the road, which previously had been impassable every spring, remained in service without a serious break in the spring of 1937, with only approximately one inch of crushed rock as a wearing course. This road in its original condition would have required at least a foot of gravel or rock base prior to bituminous surfacing, but with the selection of soils and the rolling, a total of six inch base proved sufficient for a bituminous mat.

On a project already graded on which a base and surface construction is proposed, the soil surveys are much the same as previously described, although the work necessary to procure the information is considerably less. The purpose of these surveys is chiefly to procure information which will determine the thickness of base required. As yet, we have no formula or other means of determining the exact thickness of base which will prove adequate on each type of soil encountered. The thickness specified is determined chiefly by the judgment of the Soils Engineer, which is influenced greatly by the action of similar soils under similar conditions on other projects. The thickness of base is varied on a project in accordance with the soil conditions encountered on the road. The same type of soils is different areas may require a considerable variation in the thickness of base deemed necessary to sufficiently support the surface. Conditions of frost, surface run-off, snow, rainfall, grade elevation and ditches all enter into the picture and must be considered in establishing the base thickness required. In addition to this, the Soils Engineer must anticipate unfavorable conditions if only a slight evidence is given of such a possibility.

The ranges of stabilized gravel base thicknesses most generally used for the different soils are as follows: Clay soils including sandy clays, clay loams, etc., 6″ to 9″, silt soils 6″ to 12″, sandy loams 2″ to 4″ and sands 0″ to 3″. These are, of course, the thicknesses used after all the localized areas of frost heaves, etc., have been corrected.

It has been possible in the last few years to decrease appreciably the base thickness formerly thought necessary. This has been accomplished by careful correction of all localized defective areas prior to the base construction, and by close observations of base performances on roads previously constructed. As an example, on roads where one foot of base was specified two or three years ago, 6″ or 9″ is now deemed sufficient to protect any surface that may be placed thereon. While this has partially come through our increasing knowledge of soil performance, it has also been partly due to refinements accomplished in the construction of base courses, especially through the development of stabilized sand and gravel base construction.

The Soils Engineers also make special surveys for locating binder soil for gravel stabilization. When the source and gradation of the gravel is known, an attempt is made to obtain a binder soil, which when added to the gravel, will bring the gradation of the mixture within the specified band for stabilized material. For example, with a gravel having a low percentage passing the No. 40 sieve, a binder which is high in the fine sands will prove preferable. When it is not possible to locate the most desirable type of binder, it may be possible to obtain the proper final gradation by adding a filler soil which will provide the particle sizes lacking in the gravel and binder.

In Minnesota we have attempted to use local materials for practically all aggregate base projects. Most of our sand and gravel deposits do not contain sufficient binder for compaction, so it is usually necessary to provide for stabilizing of the sand or gravel bases.

In design of stabilized base projects, it is necessary to have information as to the quantities, sources and gradation of the available gravel and sand, and the possible sources and properties of available binder soil.

The Highway Department has prospecting crews who locate gravel and sand deposits. Representable samples are obtained by digging or boring test holes, and information is obtained as to the quantity of material in each deposit. This information is assembled on a gravel pit layout sheet. All samples are submitted to the Laboratory for testing. Test results are tabulated and copies are sent to the Soils Engineers.

Having all this information available, the Soils Engineer is able to make a selection of materials, which when combined in proper proportions, will have the gradation and physical properties required for a stabilized mixture. Our specifications follow closely the recognized standard requirements for stabilized mixtures, but for the sake of economy, we are attempting to use sands or poorly graded gravels in the lower base layers.

These sands are partly stabilized or consolidated by mixing with binder soil, sprinkling and rolling. For the upper layer of base. which will serve as a temporary wearing course, we usually require stabilized gravel meeting requirements very similar to those established by the Calcium Chloride Association. Calcium chloride is usually included in the upper layer of stabilized gravel base.

The Soils Engineer submits recommendations to the Plans Division, setting forth the areas requiring any special subgrade treatments, the depth of base recommended on various sections of the project, and the proportions of the sand, gravel and binder soil from various sources which will be required for stabilization of the base courses.

During construction of stabilized base projects, the Soils Engineer usually will run some check tests on materials. If the materials vary in gradation from that upon which the design was made, alteration of the planned proportions may be necessary in order to obtain the desired final product.

In conclusion, the Minnesota practice of utilizing soil surveys in design and construction of bases for Bituminous Surfacing may be summarized as follows:

1. Treatment of localized defective areas in subgrade.
2. Obtaining uniform subgrade conditions by selection of soils in grading operations.
3. Selection of source of materials for base construction.
4. Establishing proportions of the various materials in stabilized base design.

Developments in the Fundamentals of Bituminous Construction in Washington

By

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Numerous papers written for the two previous Montana Bituminous Conferences and many Trade and Technical Magazine Articles published the past several years have stressed the necessity of adequate, stable foundations for successful bituminous treated surfaces. The highway department of the State of Washington consider the building of foundations that are well drained, firm and solid the year round of prime importance and the first fundamental factor in the construction of any type of bituminous surface on the state highway system. More attention is being given with each passing year to the construction of the foundation layers that support the bituminous mat, regardless of the type that is contemplated on any project.

It has been demonstrated on our highways that with a suitable base, the light prime treatment given new surfacing to prevent dust hazzards and the destruction of the surfacing materials, have generally remained in good condition for two or more years with very little maintenance, while on other sections that do not have adequate base support, the more expensive plant mix and penetration macadam type of surfaces have developed many soft areas and numerous frost boils which shattered the wearing surface, causing holes to develop, and requiring expensive maintenance. In nearly every case of failure the trouble can be traced to faulty foundation construction and poor drainage. This is more generally true of Western Washington where the rain fall is heavy.

Due to the natural abundance in this state of gravel deposits, rock quarries or talus slides that can be used for foundation courses with or without screening or crushing, this state has not made use of the various methods of foundation stabilization by the use of calcium chloride, emulsified asphalt or other materials. Estimates have been made on several occasions with the plan in mind of experimenting with such stabilization work, but when compared with a 10 to 14 inch sub-base course, the cost of the stabilized construction was equal to or exceeded the cost of the sub-base course and ballast or selected roadway borrow was chosen for the roadway.

In discussing the above subject it will be well to describe the methods of constructing the foundation courses and the developments that have been made during the past few years.

In order to meet all conditions that exist as to the character of the existing roadbed and its load bearing ability and the location of the roadway as to type and amount of traffic that will use the road, the Standard Specifications provide for a number of foundation and surfacing materials that may be specified. In designing the roadway sections, the location engineer utilizes suitable wayside material when available and of an approved source and in amounts as dictated by logical construction to reinforce the subgrade soil to adequately carry traffic under all weather conditions.

(a) Selected Roadway Borrow:

This borrow generally consists of naturally occurring granular material from approved sources and is restricted by broad limits as to grading. However, the mortar portions of the borrow material (Passing 10 mesh sieve) must have the physical properties approaching the requirements for the mortar of Group A-1 subgrade soil as nearly as such material is available. The maximum size of stone in selected borrow may not exceed the depth of the course and in any case not exceed six (6) inches.

(b) Ballast:

The ballast consists of crushed stone or naturally occurring granular material from approved sources and is subjected to the abrasion and sodium sulphate soundness tests. If more than 10% of the ballast passes the 10 mesh sieve the fine material must be similar to Group A-1 subgrade soil in physical properties. The maximum size of the ballast material is restricted to be not larger than will pass a 4″ screen, not more than seventy-five (75) per cent shall pass a two (2) inch screen and not less than twenty (20) per cent shall pass a one (1) inch screen.

(c) The other base and top surfacing courses available for use are sub-base course, base course and top course and can be described under one heading with the maximum sizes specified ranging from 3″ to ¾″ as shown below in the table. All materials must be from an approved source.

These materials are tested for abrasion, sodium sulphate soundness and must not contain more than 10% loosely cemented foliated stone.

When the materials are produced from gravel, the crushed gravel when separated on the ¼″, ½″, ¾″, 1″, 1½″, and 2″ screens must contain in each size not less than fifty (50) per cent by weight of fragments with at least one fractured face, the fraction passing the ¼″ screen shall contain not less than eighty (80) per cent by weight of fragments with at least one fractured face.

The table of screen tests for the above materials are as follows:

		Sub-base Course	Base Course	Top Course (a)	Top Course (b)
Passing 3″	Not less than	100%			
Passing 2½″	Not more than	90%			
	Not less than	50%			
Passing 1½″	Not more than	10%			
	Not less than		100%		
Passing 1″	Not less than			100%	
Passing ¾″	Not more than		60%		
	Not less than		40%		100%
Passing ¼″	Not more than		40%	65%	65%
	Not less than		20%	50%	50%

(a) Applies to top course material produced from ledge rock, talus or other highly angular stone.

(b) Applies to top course material produced from gravel.

(c) Filler (for surfacing).

The present specifications state that the filler material for binding the foundation and surfacing courses shall be of such size that not less than 90% will pass a 1/4″ screen and not less than 75% will pass a 10 mesh sieve. In addition the material passing the 10 mesh sieve, when combined with the fine material from the surfacing courses, shall have the physical characteristics as nearly as possible of Group A-1 sub-grade soils.

METHOD OF CONSTRUCTION

In order that the wheel loads of traffic will be distributed sufficiently over the subgrade and the bearing power of the subgrade soil is not overtaxed, the foundation courses consisting of selected roadway borrow, ballast or sub-base course are spread on the subgrade to the thickness designed for each project. In order to bind and key up the ballast and sub-base courses "Base Course" rock is used where needed. To further bind and key these two courses it is specified a filler material be spread lightly over such areas and broomed and rolled. The foundation courses are spread over the entire roadway surface.

The base course rock is next spread on the roadway and if necessary to bind this course, filler material is spread over the base course in amounts as designated by the engineer, and in no event more than 15% of the total volume of the base course. Next the base course and filler material is mixed thoroughly together by blading from one side of the roadway to the opposite side and the operation repeated until the filler is thoroughly distributed. Water is sometimes added to help in the mixing process. The base course is then bladed over the roadway to the lines and grades as staked. In most cases the base course is spread across the entire surface of the roadway.

The top course material is spread in the majority of cases to the width of the traveled roadway and where needed to bind up the surface, filler material is added in small quantities, and not to exceed 15% of the total volume of top course. In some cases the whole roadway is covered with top surfacing material.

Theoretically the above method of mixing the filler material with the base and top courses should result in a dense, unyielding mass and free from inequalities, but with a filler material that is damp when excavated and containing a high percentage of clay and similar to the Group A-6 subgrade soils, invariably there will be some areas in the roadway that will soften during wet weather and be susceptible to frost boils during freezing winter weather, with the results that portions of the bituminous surface placed on the roadway will break up and require maintenance every year unless these portions of roadway are rebuilt from the subgrade to wearing surface.

Investigation of these areas disclose, in nearly every case, a concentration or pocketing of the filler material that extends from the surface down to the subgrade and which has collected water thru capillary action. Areas have been observed where the side ditches have been dry and drainage is good yet free water will be present near the surface of the roadway and considerable amounts can be drained out of the base and sub-base courses. In some cases the subgrade underneath the soft unstable areas is found to be comparatively dry, indicating the surfacing material and particularly the filler placed on the roadway is the cause of the trouble.

In order to correct this situation during the past year, fillers that contain clay material have been discarded and only sands or waste crusher screenings with characteristics of Group A-1 to A-3 subgrade soils were used for fillers. In some cases the base course was treated with a medium curing asphalt cement as a primer coat and no filler was used, with excellent results.

Filler material has been eliminated to a great extent in connection with the top course surfacing material. The roadway surface, immediately after its construction, is treated with a 0.5 gal./s.y. application of MC-2 asphalt cement to make the roadway dustless, prevent loss of top surface material and as the first step in stage construction of bituminous surfaced roads regardless of the type to be constructed at a later date.

Progress has been made in Washington during the past two years in the curtailment and total elimination of the annual spring break up of the more recently constructed bituminous types of roadways by the use of sandy fillers in the construction of foundation and base surfacing courses. It has been found that by carefully constructing the base or foundation, lighter and less expensive types of bituminous surface treatments can be utilized and better service obtained, with little maintenance expense.

COSTS

Average costs of the foundation and surfacing courses vary considerably with the location of the project. However, the average cost of constructing a twelve inch (12) to sixteen (16) inch base course which includes 6″ to 9″ of ballast or selected roadway borrow, 4″ to 5″ of base and 2″ to 3″ of top surfacing material will range from $0.34 to $0.40 per square yard.

The determination, by the laboratory, of soil constants in accordance with the A.A.S.H.O. method and the making of soil profile surveys, while not a regular routine practice as yet, is gaining favor with this department. It is believed that after making soil profile surveys and knowing the characteristics of the soil at all points along the roadway, considerable saving can be effected in the design of the foundation courses. In some places thinner foundation sections can be safely used while in others, conditions may require renewal of considerable amounts of the sub-base soil, be given special treatment or much heavier foundation designed to handle the traffic. By this method serious defects can be anticipated and not allowed to develop.

Another development which can be considered fundamental is the inclusion of the asphalt-water preferential test when considering sources of material for the production of oil rock and to determine whether or not the rock and fine material has hydrophylic or hydrophobic characteristics. Within the last year several sources of oil rock that have previously been used for road mix and seal coat construction were found to be hydrophylic in character. Some trouble has been experienced on jobs where these aggregates were used. In one case where other suitable material was not available for the improvement now under construction a heavier medium curing asphalt cement was specified in place of the slow curing cement contemplated for the road mix project. Laboratory tests on this aggregate indicated water had little effect on the medium curing cement, while the slow curing cement was displaced on the aggregate surface by water to a considerable extent.

This is just another case where the laboratory is able to anticipate trouble, or poor construction, before it happens.

CONCLUSIONS

The foregoing discussion deals mainly with the roadway layer directly underneath the bituminous surface rather than the bituminous mat itself.

In discussing fundamentals of bituminous construction it is believed the most important factor today effecting the wearing qualities and life of a bituminous type surface is the foundation. The old adage of "No chain is stronger than its weakest link," can be suitably paraphrased to "No bituminous type surface is stronger than its foundation."

Due to the almost universal use of pneumatic tired wheels on vehicles, a large percentage of failures found on bituminous types wearing surfaces is due to sub-base or base failure rather than abrasion or wearing away of the surface.

The majority of sub-base or base failures on our Washington highways are due to pockets or areas of a high capillary soil or clay underneath the bituminous wearing surface which regularly causes trouble during the winter months or wet weather.

Road foundations that do not contain clay or high capillary soil have conclusively demonstrated the past two years that they are immune to the annual spring breakup and the bituminous wearing surfaces have remained intact, resulting in very small to no maintenance costs.

As a result of study and observation the past few years, all fillers or fine aggregates with physical properties other than those required for Group A-1, A-2, or A-3 subsoils are eliminated as mediums for binding up the foundation courses and either crusher screenings or clean sand is used. In many cases a prime coat of bituminous cement is given the roadway immediately after surfacing materials are placed to bind and stabilize the roadway surface and until the wearing surface is constructed.

In most cases the highway department is paying more for clean material free from clay or high capillary soils in constructing the foundation courses, but this extra cost is repaid many times over by greatly reduced maintenance costs and a roadway is constructed that will stand up for many years without developing frost boils or soft areas each spring.

SECTION III

Developments in Practical Design and Construction of Bituminous Surfaces

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Report of Committee on Developments in Practical Design and Construction of Bituminous Surfaces

By

BERNARD E. GRAY, Chief Highway Engineer
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New York, N. Y.

The following fourteen papers were submitted to the committee and have been summarized to bring out the most important details. This arduous work was done principally by members other than the chairman, and to them should go the credit for prompt and willing acceptance of their assignments in the midst of a busy season.

I

A HOT-MIX, COLD-LAY ASPHALT MATERIAL AND AN IMPROVISED PLANT FOR ITS MANUFACTURE

By

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Abstract

Mr. G. A. Draper, in his paper "A Hot-Mix, Cold-Lay Asphalt Material and an Improvised Plant for Its Manufacture," states that Mississippi has found a solution for low cost repair for pavements using local materials.

The materials used are round glacial gravel, pit-run sand, hard asphalt cement and cut-back asphalt. The asphalt cement usually used has a 50-60 penetration. For cut-back, RC-1, with a viscosity of about 150, penetration of base of about 120 and naphtha with an end point of about 430, is used.

For mixing small quantities of this material a regular drum concrete mixer, heated to 250-300° F. with torch type kerosene burners, is used. After the aggregates are heated the torches are removed and the hot asphaltic cement added and mixed for about two minutes. Then the cut-back is slowly added. As there is some danger of fire at this point precautions should be taken to see that there are no open flames near the mixer.

The proportions of the two asphalts depend on the workability period desired. For a workability period of three or four hours equal proportions are used. Where longer workability is desired, the proportion of cut-back is increased and the asphalt cement decreased accordingly. As soon as the rolling is completed the road can be opened to rubber-tired traffic.

This material has been used for thin repairs as well as bases, in some cases twelve inches thick, and has not shown any signs of corrugation or shoving after three years service.

Production has been increased by using a portable dryer and a mixer heated with natural gas. Mr. Draper will be glad to furnish detailed information about this plant and material to any desiring it.

Comment by Mr. Stanton

Mr. Draper's account of the portable mixer for the preparation of patching material is quite interesting. Some work of this sort has been done in California using a small pug mill type mounted on a truck. Application has been rather limited, however, due to the fact that premixed material may be obtained from commercial plants which are widely scattered throughout the state. The premix material which has been most satisfactory throughout California is a dense graded aggregate using either SC-4 or ROMC-3 liquid asphalt as binder. These materials may be stockpiled for long periods and still remain workable.

A few years ago a short experimental stretch was laid using the so-called "Fin-Mix" process, in which the aggregate is coated with hard asphalt and then given an application of SC-2 oil. Results were fairly satisfactory; however, the mixing process was unduly long and no material advantage was evident over the standard procedures.

II

A CORRELATION OF RESEARCH TO PRACTICE IN BITUMINOUS SURFACING

By

N. M. FINKBINER, Engineer of Materials,
Oregon State Highway Commission

Abstract

Mr. Finkbiner compares the open-graded type bituminous pavement to dense mixes. He believes that either a quite open or tightly closed mixture should be used; intermediate types are considered to be vulnerable to freezing.

Bituminous concrete development is traced from rich mixtures required to withstand steel shod traffic, to the dry mixes now in general use. The high speed of vehicles requires a nonskid surface, which in Oregon is secured by a coated chip procedure. Open-graded mixes are particularly effective when maintaining a non-skid wearing surface. The following grading is recommended as being the most satisfactory with RC-4 asphalt binder:

Passing ¾″ and retained on ¼″	45%-55%
Passing ¼″ and retained on #10	30%-36%
Passing #10 and retained on #200	8%-14%
Passing #200	0 - 2%
RC-4 cut-back asphalt	4%- 6%

When light traffic roads were first surfaced by the road mix method, progressing from a dust oil (SC-1A) to the SC-2 grade, the difficulty in controlling the percentage of filler led to the adoption of RC-3 cut-back asphalt, with carefully controlled quantities of pit run aggregate. He concludes that "The best results in a bituminous mixture are obtained from the use of the hardest possible asphalt which can be manipulated under specific conditions . . . without becoming too brittle." RC-3 asphalt is very satisfactory for road mixing, requires very little filler, and setting is so rapid that a seal coat may be applied within three days.

Comment by Mr. Stanton

California has had very little experience with RC type of binder. Scattered trials indicate, however, that quick-setting cut-backs can often be used to advantage, particularly in cold weather work where drying out or setting up of a kerosene cut-back is often slow. The elimination of fines when using a hard asphalt base is in accord with our experience. The same principle of design is followed in this state; namely, where fines are lacking or eliminated, a harder asphalt binder is used.

In view of the fact that the bulk of our construction is of the dense graded type, using about 7% filler, we distinctly favor the ROMC type of cut-back, which uses a 90-95 road oil as a base.

Comment by Mr. Lockridge

The first paragraph brings out a thought which is worthy of some study; namely, that "either a quite open or a tightly closed mix should be used, since danger from freezing is much increased in a semi-tight mix which contains insufficient outlets for the expansion of the water in forming ice." The matter of securing a non-skid surface is on the mind of every highway engineer today and, while the principles involved in accomplishing a non-skid surface are substantially the same in every locality, the details will vary considerably due to differences in temperature, rainfall, grades and alignments. The thought expressed throughout portion of paper under heading "Road Mix Using RC-3 Cut-Back Asphalt," wherein accurate control in the grading of aggregate is required, means everything in the results obtained.

III

DEVELOPMENTS IN PRACTICAL DESIGN AND CONSTRUCTION OF BITUMINOUS SURFACES IN IOWA

By

V. G. GOULD, Assistant Bituminous Engineer

Abstract

A review of procedure is furnished for the period 1930 to 1936 inclusive, and the practice for 1937 is defined.

Initially the type of surfacing was confined to light mats, utilizing the loose material on the roadbed in combination with road oil to form a type of surface treatment. Subsequently the strengthening of the base prior to treatment was deemed advisable and was accomplished by placing additional courses of base material consisting of pit-run gravel or crushed gravel with soil binder, or crushed rock with chips or dust. Following the construction of the base course, cover material was added to such loose material as was available on the roadbed to allow a quantity of 250 cubic yards to the mile for the surface treatment. Later refinements provided that loose material on the roadbed would not be incorporated in the bituminous course but would be swept to the shoulders, and that a definitely graded cover material would be placed at a uniform rate per square yard. The 1936 practice consisted of sweeping the roadbed free of loose material and dust, priming at the rate of 0.5 gallon per square yard, and applying 60 pounds of aggregate and 0.6 gallon of bitumen in two applications, heavy viscosity cut-back asphalts being used, generally of the MC-4 and MC-5 and SC-7 and SC-8 grades.

Similar types of treatment will be applied in 1937 as well as an experimental mat project. Experimental base projects utilizing various forms of stabilizing agents will also be constructed for the purpose of establishing alternate construction procedure and cost.

Stage construction is favored.

IV

PROGRESS IN RESEARCH PLANS, THE CORRELATION OF RESEARCH, DEVELOPMENTS IN THE FUNDAMENTALS AND CONSTRUCTION OF BITUMINOUS SURFACES IN NORTH DAKOTA

By

H. G. GROVES, Bituminous and Soils Engineer

Abstract

Mr. Groves traces development in North Dakota from the road-mix type in 1929 to the present tendency toward the plant-mix type. Costs of plant and road-mix are approximately the same. Plant-mix permits a longer working season and the use of road oil of high viscosity. Most failures have been traced to poor foundations, with the worst conditions along the edge of the pavement.

Changes are proposed in the base construction, following experiments with different types of rollers. Pneumatic type rollers gave compaction, but it required final rolling with smooth steel tired rollers to develop a smooth surface for the application of tack coat. A light application of water to the base helped penetration of the tack coat. Present practice requires a 6″ loose measurement of gravel base on the A-4 to A-8 type of soil, and 4½″ on A-1 to A-3 type of soil. The base is to be built 3 feet wider than the bituminous surfacing. It is proposed to adopt a mat 1½″ in thickness in place of the 2½″, for reason of economy.

Alternate types of light treatment include application of tar, MC-2, or SC-2 to the stabilized base, in certain cases with a seal coat of RC-2, covered with approximately 12 pounds of sand per square yard, to be placed after the tack coat.

Comment by Mr. Stanton

Mr. Groves' statement that in North Dakota the tendency is more and more toward the plant-mix type rather than road-mix parallels development in this state. Cost of the two types is approximately the same in California.

Mr. Groves refers to the use of pneumatic rollers. Rollers of this type are now being used in California, particularly in the southern area (Dist. XI) for compacting bituminous mixtures. Results are very satisfactory.

Mr. Groves notes that a light application of water on a gravel base before the application of the tack coat makes for better penetration. Some years ago we conducted an investigation in the form of a questionnaire circulated among the field men both in the maintenance and construction departments. One of the questions asked concerned the desirability of wetting the roadbed before the application of oil as a prime coat or seal coat. The results showed that there was an even division of opinion; one-half firmly believed that preliminary wetting of the subgrade was essential, and the other half insisted that the roadbed should be as dry as possible. While satisfactory results were being obtained with both methods, there appeared to be some question as to whether or not it was an important consideration.

V

BITUMINOUS CONCRETE CONSTRUCTION

By

W. J. LAWSON,
Assistant Chief Highway Engineer, New Brunswick

Abstract

Current practice provides for stabilizing the subgrade, where necessary, by lowering the water table through the systematic placing of tile under-drains. Standard base course design now consists of constructing a gravel sub-base, 4 inches or more in compacted depth, as a foundation course for a bituminous base three inches in thickness. The bituminous mixture is plant mixed using a 70 to 80 penetration asphalt cement and either crushed gravel or a crushed stone is satisfactory as course aggregate. The specification provides for 100% of the material passing the 1¼ inch sieve with 2% to 8% passing the No. 200 mesh sieve and an asphaltic content of 4% to 6%.

Work awarded in 1934 specified the placing of a one inch sheet asphalt wearing course with an asphaltic content of 9½% to 12%, using 70 to 80 penetration asphalt, and with all aggregate passing the No. 8 mesh sieve and 10% to 20% passing the No. 200 mesh sieve. In 1935 a hot mixed surface seal coat was substituted for the sheet asphalt wearing course and ap-

plied in the approximate amount of 30 pounds to the square yard. The mixture carries an asphaltic content of 8½% to 12%, with all aggregate passing the No. 4 mesh sieve and 4% to 18% passing the No. 200 mesh sieve.

A cold lay mixture is provided where shipment is required by introducing a liquefying agent with an initial boiling point of not less than 200 and a final boiling point of not more than 500 degrees Fahrenheit.

The sub-base is primed prior to the placing of the bituminous base course and the surface seal coat when hot mixed is applied to the base course before the latter becomes chilled. Side forms and self-propelled spreader boxes and finishing machines are required.

A pavement width of 20 feet is designated.

VI

DEVELOPMENTS IN PRACTICAL DESIGN AND CONSTRUCTION OF BITUMINOUS SURFACES IN MONTANA

By

W. J. LEARY, Division Engineer

Abstract

Montana engineers were confronted with a difficult problem "to get out of the mud" and improve a large mileage of highways with limited funds. Construction procedure and specifications are furnished, covering the work since 1929. In the early stages in Montana program, SC-2 oil was used, in road-mix construction, with pavements 3″ thick and 20′ wide, traffic-compacted. In 1932, a heavier grade of oil was substituted, corresponding to SC-3. This oil was used in all road-mix construction throughout 1933-34. A typical grading specification is as follows:

Passing ¾″ screen (circular)	100%
Passing ½″ screen (circular)	40%- 65%
Passing a 10-mesh sieve	30%- 55%
Passing a 40-mesh sieve	15%- 35%
Passing a 200-mesh sieve	5%- 15%

Surfaces were sealed with RC-1 and with SC-3.

In the last two years, the trend in all road-mix work has been to MC-2 or 3 cut-back. MC-3 is found to be difficult to process in cool weather.

The first plant-mix work was done in 1931, using essentially the same grading specifications, utilizing native decomposed granite sand with SC-3 oil. In 1935 a section was laid using 95+ road oil, with a grading similar to that given above. Finishing the surface proved to be difficult. Experimental sections varying the filler content indicated that a range from 5% to 20% was satisfactory. MC-4 and MC-5 cut-back mixes are satisfactory, but there was a tendency to make these mixes too lean, which caused ravelling. MC-1 has been substituted for SC-2 in the first application for surface or blotter treatments. This surface treatment has been constructed for approximately $800 per mile.

Mr. Leary concludes with four questions rather than conclusions, which are as follows:

1. Which will give the better riding surface, an improved type of spreader or motor patrols with a long wheel base?
2. Is the saving incurred by using an RC-1 paint seal worth the elimination of the non-skid effect of a seal with a heavier oil or cut-back covered with sand and chips?
3. If the subgrade is constructed correctly, would it not be more economical to use a heavy grade of SC oil rather than a heavy grade of MC or RC cut-back?
4. Does the thickness of the mat make a great deal of difference if the subgrade is compacted correctly or if so, where is the dividing line with reference to the amount of traffic?

Comment by Mr. Stanton

Mr. Leary's outline indicates that work in Montana has followed a general trend throughout the west, with a change from slow curing road oils of the SC-2 type to heavier grades such as MC-3 and MC-4 cut-back.

It is to be regretted that Mr. Leary has not included more detailed comments on the relative suitability of the various types, and the service rendered compared to the cost of construction and maintenance.

Plant mix projects using native decomposed granite sand have a special interest. One or two sections of this type have been constructed in California and have been highly successful. It would seem that this type of construction might be utilized to a greater extent where granite sands are readily available. Projects both in California and Nevada have indicated that 95+ road oil or approximately 200 penetration "E" grade asphalt is too heavy to be laid successfully with blade equipment. While we have one section in California in which 150-200 penetration grade was used as binder which has given excellent service and is very smooth riding, nevertheless the difficulties in placing were such that we were not encouraged to repeat the experiment. The new types of power spreaders eliminate these objections and make this type of construction practicable.

Taking up the questions propounded by Mr. Leary, the following answers would be indicated from California experience:

1. Best riding surfaces of any type of pavement have been secured with motor patrol with a long wheel base, with the additional absolutely essential requirement, however, that a skilled and gifted operator be at the controls.

2. We have used no RC-1 paint seal, but the elimination of sand and chips is believed to be distinctly worthwhile, and the non-skid features can be retained if the surface to be treated contains sufficient coarse aggregate.

3. We have a vast mileage of roads built with SC-2 oil as binder which have carried traffic for ten years or more with little maintenance. Oils of this type will undoubtedly meet all requirements and give the greatest economy in many locations. They are more suited for arid regions with good drainage and little precipitation than for regions of heavy rainfall or snow removal.

4. The thickness of the mat makes little difference if foundation conditions are perfect. However, there is a definite practical limit in the accuracy of spreading road-mix surfacing. Taking all factors into consideration, it is believed that for general conditions a 3″ thickness is the most satisfactory although successful pavements have been built with less.

Comment by Mr. Lockridge

Mr. Leary brings out a mistake that has been made at one time or another by practically all highway officials. Pressure from local communities and politicians has frequently caused programs to be set up hurriedly, which were soon to prove a disappointment to all concerned. As we improve a road the traffic increases, with the result that such improvement as is made may be entirely inadequate. Under "Road-Mix," it would seem that a mat 3″ in thickness, traffic compacted, would be reaching the upper limit so far as depth is concerned. The contract referred to certainly was quite reasonable if a suitable 3″ mat 20′ in width was secured at the price of $825.00 per mile. This is more noticeable when compared with another project providing 1½″ mat 22′ in width which cost $2,700.00 per mile. Calling for use of MC-2 or 3 on all road-mix work is contrary to the expression found in several of the other papers. I note with interest the remarks about thickened edge. It is true there would be some grief in connection with this work, but I am wondering if it would not be worthwhile in many instances. As more refinement is put into the work and a better type of material is used, it seems that the price increases quite rapidly. This is indicated by the statement that 24′ surface 2½″ thick cost $9,000.00 per mile. Four questions are asked. I should say a good answer to the first question would be that **we need both.** I think the answer to the second question should be **no.** To answer the third question, I believe **the SC oil preferable.** In answering the fourth question, **I believe the location should be taken into consideration; if in a locality where the spring thaw-out creates an unstable condition, I think a heavier wearing surface might "get by," whereas the real thin mat would go to pieces. I do not believe the amount of traffic would make a great deal of difference except during the short period following thaw-out.**

VII

DEVELOPMENTS IN PRACTICAL DESIGN AND CONSTRUCTION OF BITUMINUOS SURFACES

By

J. E. LLOYD,

Oil Construction Engineer, Wyoming

Abstract

Old gravel roads laid 18-20 feet wide, 6″ thick; as late as 1927, intention to bring whole system to gravel standard in

following ten year period. Loss by erosion and greatly increased cost of maintaining untreated surfaces, however, led to experiments with road oiling to preserve work already done, in 1928 some 85 miles being surfaced with road-mix type. Up to 1931 such work was done with state forces, and since that date mostly by contract. At present time (1937) there are 2,630 miles of bituminous surfaces (72%) on the state system.

Early mats were 20′ wide 3″ thick, using 60-70 road oil. Later 70-75 (SC-3) was employed for road-mix, 75-80 for plant-mix. Aggregate obtained from road surface was often lacking in quantity and quality. Failures occurred usually along shoulders due in part to faulty drainage but mainly to insufficient depth of gravel.

Present practice provides adequate drainage, careful evaluation of subgrade and placement of depth of gravel sufficient for the particular location. Often 6″-12″ pit-run gravel is placed as sub-base for the crushed aggregate surface to follow. Base courses are laid full width of roadbed. MC-1 at .3 to .5 gallon is used as prime coat. Mats are 1½″ in depth for light traffic routes, 2½″ in depth for heavy traffic. Gravel shoulders are generally constructed and surface seal coats using RC-2 either with or without sand cover is usual practice.

The trend is toward use of cut-back asphalts in road mixing, first MC-2 and later MC-3. The writer believes mixes are more stable and durable using cut-backs than with SC products, and that even with higher initial costs the annual cost will be lower.

The usual road equipment for mixing is used except that regardless of plant or road-mix, final spreading and blending is done with blade grader.

The principal advance in design is in respect to better subgrades and base courses. The selection of bituminous material is still a matter of opinion, although climatic conditions play an important part, as well as character of aggregate. Competent field inspection is necessary to carry out the office and laboratory design.

VIII

DEVELOPMENTS IN PRACTICAL DESIGN AND CONSTRUCTION OF BITUMINOUS MAT SURFACES IN KANSAS

By

A. B. NUSS,
State Highway Engineer

Abstract

The necessity of providing an adequate base or support is stressed, with the recommendation that the soil base be classified and its load carrying capacity determined. Proper drainage is advanced as often a partial substitute for stabilization, with flat side slopes or wide berms being deemed a requisite. It is recommended that the subgrade be designed to carry the wheel load as if the load were applied directly to the subgrade, it not being considered that bituminous mats less than 2 inches in depth aid in the distribution of the load to the subgrade. (Note: In reading this paper, the inference is obtained that the mat is placed directly upon the subgrade, without a base course of granular material.)

A minimum distribution of 1200 tons of aggregate per mile for the bituminous course is recommended, with a distribution of 1500 tons to 2000 tons preferred, the mat not to be less than 24 feet in finished width.

Two sizings of dense graded aggregate are specified, one sizing with 100% passing the 1 inch sieve and 8% to 15% passing the 200 mesh sieve and the other with 100% passing the 1½ inch sieve and 5% to 10% passing the 200 mesh sieve.

A mat with the least amount of voids obtainable is recommended and the use of an SC cut-back asphalt as the bituminous agent is definitely preferred. Sealing, immediate or deferred, with an RC cut-back asphalt is considered good practice.

Stage construction is not recommended. No mention is made as to methods of mixing or type of equipment employed.

Comment by Mr. Lockridge

Suitable base and proper drainage are stressed, but I find no mention of the use of perforated pipe. We find this means of treating undesirable subgrades very practical in Indiana. In reference to sealing an SC oil mat with RC cut-back, I think the matter of **not sealing** for, at least, one year and perhaps two should be stressed. Reference is made to never using SC road oil when the temperature is below 65° F. I believe that would be good practice, however fear that if strictly adhered to very little oil mat would be laid in the State of Indiana. I cannot agree wholly with Mr. Nuss in his paragraph relative to stage construction. Personally, I feel that, if the proper conditions have been provided as listed in first paragraph under "Design," stage construction is quite desirable in bituminous type construction in general.

IX

DEVELOPMENTS IN FUNDAMENTALS OF BITUMINOUS CONSTRUCTION

By

J. R. PHILLIPS,
District Engineer, Wyoming

Abstract

Mr. Phillips emphasizes the inescapable connection between design and public demand for greater and greater mileages. Immediately after first oiled surfaces were constructed (largely as experiments) the public desire for immediate extension of such types led to surfacing roads which had heaviest traffic and probably thinnest metal. Various oils and asphalt products were employed. By 1930, it was possible to compare various projects, and the importance of subgrade studies became evident.

Roadbeds were widened from 26 to 36 feet on heavy traffic routes, and from 26 to 30 on others. Soil surveys were made wherever there was any question as to stability, and sub-bases of pit-run gravel installed.

Failures formerly occurred principally in the outside thirds of the cross-section. This has been corrected by making the base 6″-4½″-6″ in depth, and few failures have occurred since. For exceptionally bad gumbo soils 18″ depth has been placed.

The trend is toward use of cut-back asphalts even though from 1 to 1½% more is required in using MC-3 as compared with SC-3. However, there is some thought of using SC-3 again

on light traffic roads where A-1, A-2 or A-3 soils are encountered, largely because of lower initial cost. The MC products produce a harsh mix having high non-skid qualities. Some doubt at first as to maintenance of MC surfaces with one-man graders, but experience indicates that remixing (where necessary) is readily accomplished.

However, the mat is a wearing surface only, the base and subgrade actually carrying the load, and when the latter are properly designed and constructed the surface seldom requires remixing.

X

HARDENING OF ASPHALTIC CEMENT IN ASPHALTIC CONCRETE PAVEMENTS

By

J. W. POWERS,

Engineer of Materials, Arizona

Abstract

Mr. Powers has investigated the properties of asphalt in both cracked and satisfactory asphalt pavements in Arizona. Asphalts were recovered from the mixes by the Abson method. Results indicate that most pavements in which the asphalt has a penetration of 10 or less are cracked or showing signs of brittleness. Pavements containing asphalt higher than 10 penetration are in good condition.

Further investigations were carried out to determine the effect of plant temperatures, with the conclusion that within the range of 265° to 305° F. the penetration of the extracted asphalt varied little from mixes kept in sealed containers. Studies were made of the effect of aging, samples showing a loss of 32 points in penetration in 106 days' storage in air tight containers. The study is not yet complete.

Mr. Powers believes that asphalts of softer grade will eliminate the tendency of pavements to crack.

Comment by Mr. Stanton

Mr. Powers' article describing the investigation of asphalt pavements, with determination of the condition of the asphalt binder is interesting and very timely. Thus far we have little experimental data on the condition of asphalts in existing pavements in California. There is little doubt that there is considerable difference in the manner in which asphalts from different sources are hardened due to temperature and exposure. A few scattered tests in which the asphalt was recovered by the Abson method have indicated that the penetration of the asphalt drops to less than 60% of the original during the mixing period in the pug mill. It is our hope to carry on some work along these lines, particularly to find out whether there is any greater change in the quality of the asphalt due to exposure to sunlight than is the case with samples in sealed containers.

It is also our viewpoint that asphalt pavements would be much benefited by the use of asphalts of not less than 100 penetration. We have recently completed an experimental section in which were placed asphalts of 50-60, 76, 110, 170 and 225 penetration, in alternate sections. The complete report is now being prepared.

Comment by Mr. Litehiser

A similar study by our laboratory verifies the results obtained by Mr. Powers with perhaps one exception. Although we have not investigated the loss in penetration on materials stored in air tight containers, we have investigated the loss during mixing at a range of temperatures at several different plants and find this loss to be great enough to cause some concern.

XI

BITUMINOUS MIX CONSTRUCTION IN VERMONT

By

A. J. RUNNALS,
Road Engineer

Abstract

The principle of providing an adequate support for the bituminous course is recognized, with a variable depth specified. The base course or sub-base, as termed, is also carried to the full width of the roadway. The necessity of providing proper drainage is emphasized.

Current practice provides for a bituminous course 2½ inches in compacted thickness and 20 feet in width. Either a crushed gravel or a crushed stone aggregate is deemed satisfactory, with a sizing ranging from the 1¾ inch to the No. 4 sieve. Uniformity in the grading of the aggregate is considered essential and all fines are excluded from the mix.

The sub-base is primed with tar, and tar or a rapid curing cut-back asphalt is used as the mixing agent, the heavier grades being preferred. Road-mix is specified and is accomplished by means of the "retread machine" or by blade graders. Following the spreading and rolling operations a filler is spread over the entire surface area for the purpose of filling the voids. Washed sand is used as filler in combination with tar and ¾ inch to ¼ inch stone in combination with cut-back asphalt. Subsequent to the filling of the surface voids, and to the elapse of a proper curing period, the final operation is performed in the application of a seal coat. Cover chips are graded between the ⅝ inch and No. 4 sieves and are used in conjunction with either tar or cut-back asphalt.

Comment by Mr. Lockridge

This paper hits the nail on the head wherein it is stated that "No surface course, no matter how well constructed, will prove an economical and serviceable type of surface unless it is placed on adequate sub-base, i.e., a sub-base of sufficient depth and width for the road in question." I can hardly agree that 2½″ crown should be provided on a 20 foot width of main line highway. It is true that we have some such surfaces in Indiana but, in general, I feel that less crown will prove more satisfactory where the road is otherwise properly designed. There is correct emphasis in the matter of mixing. All aggregates should be thoroughly coated if we want to insure the surface against ravelling. I question the statement wherein it is required to remove aggregate not properly coated by hand shovels. I feel that as an alternate there are instances where hand spray may take care of this fault more economically and leave perhaps a better riding surface. The provision for smoothing with long wheel base grader should seem to secure a better riding surface than set up wherein a tolerance of ½″ in 10 feet is permitted. I believe this tolerance should be reduced to ¼″ in 10 feet. I agree that the "better grading of the aggregate, more rigid requirements in washing of the aggregate, better equipment for mixing operations and the use of heavier bituminous materials in the mix and seal are advances in mixed-in-place construction."

XII

DEVELOPMENTS IN PRACTICAL DESIGN AND CONSTRUCTION OF BITUMINOUS SURFACES

By

H. G. SMITH,
Construction Engineer, Oregon

Abstract

It has been found necessary to increase the stability of soils even under the heavier pavements and the use of a ballast of stone, talus rock, or gravel is considered the most economical and satisfactory manner of accomplishing the result. The depth of base course is varied with the type of soil and the gradation of the ballast material varied with the type of surface course, the more open graded materials being placed under pavements of adequate slab strength and the denser graded materials being placed under surface courses with little load transfer value. The open graded ballast is considered the most advantageous for affording complete drainage but the denser graded material is considered essential under light surface courses to prevent displacement of the base under traffic. It is recommended that caution be exercised in the use of clay bound material or the use of calcium chloride as a stabilizer where deliquescent alkalies occur in the soil material.

The type of bituminous course specified is predicated on the theory that the design must be correlated with the method of maintenance to be employed, the extra gang hot plant procedure being standard and of such character and refinement that the condition of the surface course is maintained in a state equivalent to its original construction. The bituminous surface course "is designed adequate for its traffic, or as a step in stage construction as traffic increases, and no design contemplates reworking or remixing at any future time."

Ultra flexible types of surfacing have been found inadequate and hot asphalt is used in penetration work "as neither cutbacks nor emulsions have shown comparable ability to hold

aggregate and have been discarded except for prime or seal coats in special instances or for patching during the winter season.''

Asphalt from California petroleum is used exclusively and is of 50-60 penetration in asphaltic concrete and 120-150 penetration in macadam, with road oil being generally used for the lighter surface treatments. These grades are found satisfactory for use throughout the state regardless of temperature ranges of minus 50 degrees to plus 110 degrees Fahrenheit.

Asphaltic concrete pavements are specified only on routes carrying traffic in excess of 1500 vehicles per day. Three general classes are employed, varying in gradation and asphaltic content. For base courses of more than 2 inch depth a 2¼ inch maximum size of aggregate is used with 2% to 4% passing the 200 mesh sieve and an asphaltic content of 3% to 5%. For thin base courses or for wearing surfaces with a coated screening surface finish a 1¼ inch maximum size of aggregate is used with 3% to 6% passing the 200 mesh sieve and an asphaltic content of 4½% to 6½%. For thin smoothing courses a ¾ inch maximum size of aggregate is used with 4% to 7% passing the 200 mesh sieve and an asphaltic content of 5% to 8%. Surface finish coats are applied of hot mixtures of ¾ inch to ¼ inch aggregate coated with 2% of asphalt at the rate of about 6 pounds per square yard. As an alternate to the hot asphalt finish coat mixture a rapid curing cut-back asphalt mixture is used composed of a ¾ inch maximum size of aggregate with 0% to 2% passing the 200 mesh sieve and a liquid asphaltic content of the RC-4 grade of 4% to 6%. Mechanical spreading and finishing machines are required on all jobs and either crushed stone or crushed gravel is acceptable as aggregate. Non-skid finish coats in the form of a surface treatment are also placed on the older existent mileage as required, generally in three applications and to a depth of 1⅛ inches, using hot asphalt as the bituminous agent.

Bituminous macadam is the preferred construction where pavement is not considered justified, and under alternate specifications is placed in either one course or three courses to a depth of 2¾ inches using a hot asphalt. A double seal is specified, using hot asphalt in the first application and cut-back asphalt or emulsified asphalt in the second application. As an alternate a single seal treatment of equivalent weight is employed using a hot asphalt as the binder agent.

An oil mat surface treatment is specified on routes carrying less than one thousand vehicles per day and is constructed in two applications to a depth of 1¼ inches using a No. 3 road oil in the amount of 0.65 gallon per square yard. A seal coat of road oil with cover chips, is also specified, making the total quantities per square yard for the entire treatment approximate 1.05 gallons of road oil and 0.046 cubic yard of aggregate. For very light traffic a single treatment plus a seal coat is constructed, with total quantities per square yard approximating 0.7 gallon of road oil and 0.03 cubic yard of aggregate.

Road-mix surface treatments are confined to the arid sections of the state where the available material is more adapted to mixing than to surface treatment but only a limited amount of this type of construction has been used. Rapid curing cutback asphalts of the heavier grades are specified, it being considered that it is impossible to evaporate, or for the aggregate to absorb, the entire amount of the kerosene cut-back thus affording a dangerous lubricating agent to eventually cause corrugations and traffic grooves. It is further considered "that asphalts of such ductility as result from MC products are unstable for permanent road surfacing and will eventually cause inherent defects in the road which will necessitate scarifying." The mat is constructed to a depth of 2½ inches and is composed of a semi-dense graded material with not more than 3% passing the No. 200 mesh sieve. The mat is subsequently sealed with a heavy grade of cut-back asphalt.

XIII

DEVELOPMENT IN THE FUNDAMENTALS OF BITUMINOUS CONSTRUCTION IN WASHINGTON

By

J. L. STACKHOUSE,
Construction Assistant

Abstract

Experience has demonstrated that light prime coats on sound base have remained in good condition for several years, while on inadequate bases, good plant-mix surfaces have failed. In

nearly every case road surface failures may be traced to faulty foundation or poor drainage.

The state has an abundance of gravel, talus rock and other aggregate cheaply available so that through their use is obtained the cheapest method of stabilization.

Where selected borrow is obtained for improving the subgrade condition, requirement for fractions passing 10-mesh sieve is substantially that for A-1 soil.

The same is true of crushed stone ballast if more than 10% passes 10-mesh sieve.

For gravel, sizes above ¼″ must contain at least 50% particles with one fractured face and passing ¼″, 8% so crushed.

The table of screen tests for the above materials are as follows:

		Sub-base Course	Base Course	Top Course (a)	Top Course (b)
Passing 3″	Not less than	100%			
Passing 2½″	Not more than	90%			
	Not less than	50%			
Passing 1½″	Not more than	10%			
	Not less than		100%		
Passing 1″	Not less than			100%	
Passing ¾″	Not more than		60%		
	Not less than		40%		100%
Passing ¼″	Not more than		40%	65%	65%
	Not less than		20%	50%	50%

(a) Applies to top course material produced from ledge rock, talus or other highly angular stone.

(b) Applies to top course material produced from gravel.

Great pains are taken to construct a tight base, and filler is used when necessary. However, care to prevent pockets of filler material which may draw up water from the subgrade by capillary pressure is required, as failures in the mat surface have often been so caused. To prevent such action all clay materials are rejected and only sand and crusher fines corresponding to A-1, A-2 or A-3 soils are now permitted.

Filler material in top course has been largely eliminated, and a .5 gallon treatment of MC-2 is applied instead as binder.

Spring break-up has been eliminated where new surfaces have been built with these changes.

The average cost of 12″ to 16″ foundation (made up of 6″

to 9″ ballast or selected borrow, 4″ to 5″ of base, and 2″ to 3″ of top surfacing course), is from $0.34 to $0.40 per square yard.

Soil surveys and adjustment in design accordingly is gaining favor as standard procedure and the variation in base thickness according to natural soil support is sound economy.

Studies to determine character of aggregate and affinity for asphalt are important and will often prevent use of material which might cause failure. Instances are cited where the MC products would adhere to a given aggregate while SC products were stripped.

XIV

STUDIES OF STABILIZED SOIL AGGREGATE MIXTURES

By

A. E. STODDARD,
Engineer Materials and Tests, Iowa

Abstract

Mr. Stoddard stresses importance of subgrade design and that present practice is to obtain maximum density through gradation of particle size, character of binder soil, plasticity index, etc.

Beginning with 1935 the Laboratory undertook study of stabilized soil-aggregate mixtures, representing the six principal soil types found in Iowa. Analyses are shown in tables, also mixtures with gravels and sands. These mixtures were molded into 2″ x 2″ x 14″ beams and tested under variable moisture conditions. Correlation of Laboratory and field studies is also obtained.

Experiments are reported in respect to bituminous primers, and variation in behavior with various moisture contents.

From results at hand, it appears that some beam strength is developed if the moisture content can be reduced below 50% of that required for optimum moisture at time of placing the mixture. There is possibility that priming the subgrade contributes materially to maintenance of low moisture content.

Comment by Mr. Zass
On Practice in Arkansas

Careful attention is directed toward securing adequate support for the bituminous surface course. The soil classification of the subgrade is determined and divided into two general groupings for the assumption of bearing power under the most adverse conditions, the bearing power of the better type soils being assumed at 10 pounds per square inch and that of the poorer type at five pounds per square inch. These values are subject to further modifications dependent on particular conditions evident for the specific project. The wheel load is considered as being distributed from the area of contact of tire and surfacing to the subgrade through the depth of both the surface course and the base course on a slope of 45 degrees and sufficient thickness is accorded the design that the assumed unit stress of the subgrade will not be exceeded. It is recognized that the quality of binder in the sand-soil or clay-bound gravel mixtures has a vital effect on the stability of the base course and limiting values are being studied, with the thought advanced that perhaps a liquid limit of 30 and a plasticity index of 12 should be the maximum allowable. The volume of soil mortar in the mixture in relation to the whole is an additional factor to be considered in designating limiting values.

The sand-soil or clay bound gravel base is the predominant non-rigid type of base specified although waterbound macadam is used to some extent where conditions justify. The former type is constructed the full width of the roadway crown and the latter 18 inches wider than the width of the surface course, the greater cost of the macadam making an increased width prohibitive.

All base courses are primed with a medium curing cut-back asphalt of the lighter grades.

Open graded mixtures of the road-mix type have been specified for a number of years and a considerable mileage is existent. Current practice provides for a surface course of 120 pounds of aggregate per square yard including cover chips for the seal coat. The bituminous agent consists of a cut-back asphalt of the RC-2 or RC-3 grade, the coarse aggregate passing the 1¼ inch sieve and retained on the No. 8 mesh sieve, and the cover chips of material passing the ⅜ inch sieve and retained on the No. 14 mesh sieve. The mixing is generally accomplished by motor patrol, although multiple blade mixers and traveling plants have been used on a number of jobs.

The development of the dense graded mixture has been more recent with a consequent lesser range of experience and observation of results. The typical section provides for 200 pounds of aggregate per square yard, not including the material for the seal coat. A cut-back asphalt of the MC-2 or MC-3 grade has been used as the bituminous agent although the use of a rapid curing cut-back is now being favored owing to the difficulty of evaporating the lower grade solvent of the MC cut-backs from the mixture and the instability resulting from a percentage retaining. Emulsified asphalts have also been used successfully with this type of aggregate. The gradation requirements of the aggregate provide for 100% of the material passing a 1¼ inch sieve and 3% to 14% passing the No. 200 mesh sieve. Coarse sand or chips are used for the seal coat, employing the lighter grades of the medium curing or rapid curing cut-back asphalts or an emulsified asphalt. The road-mix method has been used up to this time but central plant mix is being considered for the larger jobs owing to the better control obtainable. The residual asphalt content is dictated by judgment, no satisfactory formula having been yet developed.

The bituminous course is placed to a width of 20 feet to 22 feet, the latter width or wider being favored for the elimination of edge failures. Feather-edging the mat is also deemed advisable. A seal coat, either immediate or deferred, with cover material is applied to all work.

A cold lay mixture has been developed for use on small jobs where shipment is deemed practical and economical. It is central plant mixed and composed of powdered asphalt and flux, the latter having the characteristics of a liquid asphalt of the SC-2 grade. The aggregate is thoroughly coated with the asphaltic oil and combined with the asphalt powder in the proportions specified. The blend of asphalt powder and flux produces a penetration range of 60 to 100 and a ductility of 15 plus. Either an open graded or dense graded mixture can be used successfully with the type of bituminous agent.

Hot plant mixtures during the past have generally consisted of the modified Topeka type, thin courses being specified, ranging from 110 lbs. to 125 lbs. per square yard. The composition of the mixture provides for 100% of the aggregate passing the

½ inch sieve with 8% to 15% passing the No. 200 mesh sieve and an asphaltic content of 7% to 10%, a 50 to 60 penetration asphalt generally being designated. Self-propelled spreading and screeding equipment is required.

Conclusion

Comment by Mr. Gray

General

(a) In the foregoing papers the dominant note is general recognition of the need for sound foundations for bituminous surfaces. It has been strange indeed that with the care required in construction of rigid types of pavement, so much has been expected of a little gravel and oil mixed together on a winding roadbed having little or no drainage. Perhaps the remarkable thing is that these mats gave as good service as they did, and that from such beginnings all subsequent betterment has occurred.

Different states obtain base stability by a variety of methods; some calling for what appear to be rather arbitrary minimum thicknesses of crushed stone, gravel, etc. This is probably the economic procedure in most instances, but the point should not be lost sight of, that what is required is a certain minimum stability under the most adverse conditions, and that the cheapest procedure which will accomplish this end is the one to adopt. Where stone, gravel or slags are abundant, a few inches extra thickness may not add to the cost, but where they are scarce, then attention should be given to the newer methods of stabilization through densification and greater soil stability by addition of bituminous materials. This involves careful study of local resources and better evaluation of material characteristics.

(b) It is well established that a minimum width of 22 to 24 ft. makes not only a safer pavement, but one cheaper in annual cost as well, because of greater lateral dispersion of traffic and lesser maintenance as contrasted with less than 20 ft.

(c) Stage construction in the proper manner is undoubtedly economical and desirable, and where not in favor, the remedy is to correct misunderstanding through better public education. It should be evident that funds for further highway development will not again reach the lavish abundance of the twenties, and that a plan of improvement in accordance with traffic growth is imperative. Furthermore, with the greater care given to drainage and base construction, heavy surfaces formerly thought inevitable will be found no longer necessary. In the meantime the roadbed attains such stability that where additional surfacing is required, it will retain smoothness and integrity.

(d) Perhaps one more point should be stressed. An untreated surface requires more soil binder than when covered with an impervious bituminous mat. If this binder is clay, capillary moisture may accumulate in damaging amount. Therefore with clay gravels, chert, etc., such excess clay content should be reduced prior to bituminous treatment. In general, clay contents below 12% are not harmful.

Subgrade and Base Stabilization

So much information is available on this subject that no detailed comment will be made except as regards one new development. It has been realized for some time that with very fine mesh aggregate, the amount of bituminous material required for waterproofing the entire mass may be quite small. Adopting this principle, experiments have been made to waterproof a mortar composed of stone screenings and soil, and then to add this to coarse aggregate in amount sufficient to fill the voids when compacted, thus waterproofing the entire layer.

Various mixtures have been tried but so far the most durable appears to be screenings to which are added enough silt or clay to make up to 10 to 20% of total, 10% moisture, and 3% RC cut-back made from 60-70 penetration asphalt. The asphalt disappears into the mix and is not visible, but briquettes so made appear to resist water action indefinitely.

The practical value of these experiments is to be found in the procedure for placing stone base construction in fashion similar to Portland cement concrete and using the same equipment. The mixture is readily compacted by tamping, is at maximum density almost immediately and therefore will maintain itself without further settlement. Approximately one gallon of asphaltic material will be required per square yard for an 8 inch thick base.

Surface Treatments

(a) There is a trend toward substituting light road-mix methods for surface treatments, even as low as .3 gallon and 40 lbs. of aggregate per square yard in retreatment work. The aggregate is applied first, the asphalt second, and mixing and spreading accomplished with suitable multiple blade drags equipped with a strike-off screed. The advantages are constant ratio between asphalt and aggregate, thorough coating and thus little "whip-off," considerable smoothing of old high crowned surfaces, and uniform texture.

(b) Choice of bituminous material should be made in light of aggregate characteristics. Thus an RC-1 grade with porous limestone might set-up as fast as an RC-3 grade with a clean, hard, trap rock. Also the speed and volume of traffic has important bearing. In the east, RC-4 and hot asphalt cements are being widely used under such conditions. It is of course necessary that application of cover-coat and rolling follow immediately after application of bituminous material.

(c) MC products are being used increasingly as light retreatments over old, dry, cracked bituminous pavements, including sheet asphalt in cities. The kerosene cuts the old surface, will crawl down the cracks, and when covered with sand sets up in satisfactory manner. For badly cracked surfaces MC-2 is recommended, for others MC-3.

(d) A problem confronting many eastern and mid-western states is scaling of Portland cement concrete. These pavements are often inherently sound and if the scaling can be arrested, much longer service will be attained. Some experimental work in Massachusetts on a heavy traffic route appears promising. The surface is first primed with some low viscosity material such as MC-1. Then hot asphalt cement 60-70 penetration is applied at rate of .25 gallon per square yard. The cover coat consists of ¾ inch stone pre-coated with the same product used as prime coat. The priming insures adhesion of heavy asphalt, and pre-coating the cover aggregate insures complete bond.

Road-Mix Surfaces

Selection of dense graded or macadam aggregate type of road-mix should be made according to availability of cheap aggregates. The selection of grade of asphaltic material should be made according to aggregate characteristics. Instances have been noted where MC-3 was the correct product for use in a cold-laid plant-mix of crushed stone all retained on ¼″ because the chalky limestone aggregate was so immediately absorptive of the distillate. In certain sandy gravel aggregates containing little or no 200 mesh particles, but with 70% passing a ¼″, the same MC-3 product proved the most suitable binder under the particular local conditions. In general, the amount of 200 mesh particles present, either in the fine portion of the aggregate or as a coating over the coarser fragments, largely determines the kind of bituminous product to be used. It makes little difference whether the distillate evaporates or is absorbed in the mix, so long as an asphalt cement is developed which insures stability. It is probable that consistent with stability soft asphalt residues of 150 penetration or more are desirable.

Cold-Laid Plant Mix

(a) As generally agreed by the several writers, the trend toward plant-mix in place of road-mix is quite evident. The dense graded types are most used in the west; the coarser mixtures of the amiesite type in the east. In the latter area thin surfaces are often placed instead of surface treatment. However, it is doubtful if an application of less than 100 lbs. per square yard is desirable, especially where correction of a rough surface is desired. When placed as a resurfacing medium, it is good practice to spread the mixture in two courses to insure maximum smoothness.

(b) Mechanical spreaders and finishers are required by most specifications.

(c) For rural locations the placing of concrete edging has proved **undesirable**. The cost is excessive in relation to cost of surfacing, but more important, positive damage results from retention of water under the pavement.

(d) With coarse-graded mixtures, provision for waterproofing and sealing the surface should be made. Two principal methods are used; one the application of pre-coated sand between initial and final rolling, the other a light seal coat and sand cover several weeks after completion of the work. Where pre-coated sand is used, 4 to 6 lbs. per square yard are sufficient and the bitumen content should not exceed three per cent.

Penetration Macadam

Where tough hard rock is available which will stand compaction without crushing under a 12 ton roller, this type is probably the most durable of all pavements. The reason is that the stone takes the wear of traffic, and the thick films of asphalt cement hold it in place. Several states have had notable success with this type, including Oregon in the west and Massachusetts in the east. Oregon practice is notable for its multiple lift procedure which insures smoothness, while Massachusetts places the 2½″ course in one operation, but under extraordinarily close inspection. More recently hot asphalt penetration is being used as a base, followed by a thin wearing course of dense graded mixtures which can be machined to desired smoothness, or by a thin road-mix or surface treatment seal. Hot asphalt cement from 85-150 penetration, according to traffic and climate, is recommended as binder because of its greater durability.

Hot-Laid Plant Mix

(a) Asphaltic concrete and sand-asphalt mixtures are generally considered the highest type pavements. Selection within this group should depend upon availability of aggregates. Sheet asphalt has been and is principally a city street type, although many rural highways are so constructed in sand areas. Generally speaking, asphaltic concrete is cheaper and less critical to handle than sheet asphalt, and when suitable coarse aggregates are available this type is indicated.

(b) Great care should be taken to insure maximum density in the completed pavement. Initial rolling with three wheel 10 ton rollers is recommended in place of tandem rolling, the tandem roller being suitable for final rolling. Numerous studies indicate that entry of water has been responsible as a rule for failure of hot-mix surfaces, especially when temperatures dropped below critical points.

(c) Mechanical finishing is required by most states, although there is some difference of opinion in respect to type of finisher. For new pavements or resurfacing with depths over 2″, it is suggested that the type of finisher running on side forms is desirable, while for lighter depths all varieties may be employed.

(d) The design of mixtures is receiving increasing attention. Consistent with stability it is believed that as much and as soft an asphalt cement be used as possible. Traffic behavior and maintenance methods have changed greatly in recent years. Balloon tires tend to pull up a pavement instead of annealing it as did cord and solid tires. Snow removal exposes pavements to lower temperatures, and chain traffic is a deteriorating influence on any pavement. To meet these conditions it is believed that 60-70 penetration asphalt cement should be minimum hardness and softer wherever possible. On rural highways in the east, use of 85-100 penetration asphalt has eliminated cracking in a number of instances.

(e) Mr. Powers' paper on cracking develops an important item in research, but particularly one not mentioned, viz., the influence of low temperatures. He observes that no cracking occurred where 10 penetration or more was found in the extracted bitumen. Studies in eastern cities where sub-zero temperatures prevail in winter indicate that 30 penetration is the dividing line.

Conclusion

With over 80% of all improved roads surfaced with bituminous types, need for continued research is quite evident. However, in view of the rapidity with which this large mileage has been constructed and the relatively new science of soil stabilization, there is every indication that the highway engineer will be able to cope with the growing demands of traffic with even better surfaces and yet with little or no increase in cost.

Conference on Developments in Practical Design and Construction of Bituminous Surfaces

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Mr. Gray: After the splendid meeting of this morning it will be rather difficult to hold the pitch of the meeting at the same level of interest. However, I hope this will take place in the discussion that will follow the report of the committee. Not being entirely familiar with your procedure, the committee made their report by condensing some fourteen papers, the various committee members abstracting and adding their own particular comments as they saw fit. Some of these papers were also submitted to the other sections, and a number of items which are contained in the construction report have already been presented by the committee on fundamentals. It will be our endeavor to omit such portions as have been already covered, to present then the comments of committee members, after which we can have a general discussion.

I have read the formal report of the committee and I am sure that we shall have much discussion on this report.

Before the general discussion begins I want to present a neighbor who has kindly consented to talk for a few minutes on highway work in his country. Those of you who visited Mexico ten or more years ago and who have been there again in recent years know that tremendous advances have been made in that country, and I take pleasure in presenting to you Mr. Urdaneta, who is testing engineer for the Mexican Highway Department and who will talk to you on some phases of their work.

Mr. Urdaneta: Mexico

During this trip to the United States I have been learning that we have in Mexico mostly the same problems that you are having here. They may be a little harder on account of our tropical climate, and I realize from what I have seen on my way through many states and from what you are saying here that not only the kinds of asphalt in use but the choice and kind of aggregate is of first importance.

I realize that it would be a good policy to take first into account the kind of climate in which roads are going to be built, so as to fix the correct specifications for such conditions. We used to build in our country mostly one type of asphaltic pavement for building most of our highways. This type of pavement was penetration armor coat, three layers, using rapid curing emulsions. It did work fine in dry places, but as soon as we arrived at the mountainous regions we had trouble with this type and also with the plant mix type using slow curing emulsions. The last one did not break for a long time and it took two months to set. In some wet places along the coast we found that even a rapid curing emulsion, took, in the penetration work, eight hours to break. So really, I think it would be a big help to have specifications made for those conditions as we have met with. We take your standards as a guide, but I am sorry to say we have not found any definite rule for meeting such special conditions.

In spite of the above our highways constructed with rapid curing emulsions are in good shape in hot and dry places. Now, in the mountainous regions we have years when out of 360 days we have 300 rainy days and we tried plant mixing, using MC cutbacks, but we met with trouble on account of the slow evaporation of the kerosene flux, so we changed to a heavy RC-4. In all other places we have not had any trouble at all in this kind of work.

I have not any more to say but I would just like to mention that we have now good roads in Mexico; that by studying your problems we are finding a solution to ours, and it has been a great help to us to get specifications from all the highway departments of this country, and I certainly appreciate your help by answering all the questions I have made.

I would like to know if there is any way to predict the future behavior of an emulsion pavement after having been laid and if there is any heavy asphaltic product similar to RC types that can be used cold in road mixers or plant mixers, so as to try it in our own equipment which consists mainly in Cedar Rapid mixers and Jaeger mixers. I thank you for your kind attention.

Mr. Gray: Thank you. You have brought out some extremely important points. I believe that the question of time of breaking of emulsion and the conditions under which it breaks is interesting to all of us, and I am going to ask Mr. McKesson if he will answer that question that Mr. Urdaneta has raised.

Mr. McKesson: California

I haven't had a chance to talk to Mr. Urdaneta in regard to climatic conditions, except that I heard him say that they had some three hundred days of rainfall. Of course, it may be an impossible condition for mixed emulsions regardless of the type because of the absolute lack of opportunity for dehydration. In some states, particularly in Louisiana, they are laying a great deal of cold mix with emulsions, and down there they also have a great deal of rainfall, continuous in the winter time and almost continuous in the summer time, but occasionally there are periods of three or four days of a week when they get the sun for drying emulsion mixes. Down in that country they use a dense mix; they use an extremely dense-graded mix in order to get the drying and prevent damage during periods of rainfall between the drying periods. An open graded mix such as we would use in the North could not be successfully laid under most of their climatic conditions. The type used in the northern regions, in New York State, Ohio, and that territory, would not succeed in a climate such as Mr. Urdaneta described because, first, the time for dehydration would be impossibly long, and second, there would be great danger that by the time the road dried out everything would be washed off the stone.

In regions of that kind, if emulsion were used at all, I think they would probably have to use the quick setting type of emulsion and the penetration type of work. And I don't think a mixed emulsion would work under these conditions because dehydration is necessary even for cold asphalt conditions. If any mixed type would succeed, it would have to be a very densely graded mix with perhaps eight to twelve per cent over 200 mesh and the proper type of filler at that. A siliceous type of filler wouldn't be satisfactory; it would have to be powdered limestone or something of that character.

Mr. Gray: The matter of dense seal is very important. I recently have had some friendly discussion as to more correct and complete evaluation of the conditions under which the work is to be done with certain designers of the amiesite type of mix which is so widely used through all the eastern part of the country. That stone-asphalt mix, as you know, is made with a liquefier (substantially a kerosene,) a certain amount of hydrated lime, and 85 to 100 penetration asphalt. The amounts of both liquefier and lime are quite small, and at first thought it would seem that the asphalt film on the aggregate would be so thick that there would be little danger of wash from the rain. With fresh mixes, however, according to how much liquefier is used, there is not an immediate bond between the asphalt cement and the aggregate due to separation by the liquefier film, and if rain comes on a pavement almost immediately after it is laid, the asphalt may be washed off in part. Thus where heavy frequent rainfall occurs the construction of hot asphalt types may be desirable.

The principal difficulty in building a hot asphalt penetration macadam is to obtain a smooth riding surface and hence the trend toward the mixtures which may be spread mechanically. However, where aggregate is available that will stand compaction under a heavy roller without crushing and breaking, there is no pavement of any description that is more durable than hot asphalt penetration macadam.

To overcome the lack of smoothness, a practice has developed in a number of areas of the construction of what is substantially a penetration asphalt macadam base with a wearing course composed of fine graded mixture at the rate of 40 to 50 pounds per square yard, which can be graded and smoothed by the multiple blade grader or spreader so that the high structural strength of the coarser aggregate is retained. The coarse aggregate has a thick film of asphalt which resists oxidation and hardening, and the smooth riding quality of the finished surface is obtained from a relatively thin, fine mix surface. I therefore, suggest, being familiar with Mexican conditions, that for some of those high altitude situations the hot asphalt penetration type with immediate setting of the material as it cools is a very desirable way of doing work. The method also will fit in with hand methods where manual labor is low in cost.

There are a number of questions that deserve more discussion, and I am going to call first on Mr. Nuss if he will be so kind. We have asked him a number of questions today, but he will perhaps amplify a little further his statement this morning on stage construction and the reasons which induced his comments in his paper.

Mr. Nuss: Kansas

Well, the reason we haven't stage construction in Kansas—there are probably two reasons. The first is that I think every highway engineer has a very difficult problem in building jobs when he wants to. There are a lot of outside influences that affect the time or place or type of roads, that you build. And stage construction, to get the maximum out of it, must be carried on at the proper time. If your first stage is let go to a point that you have some failures in it, then your second stage, going on a failed first stage, will not give you what you would like to have in the finished product.

In Kansas when we have a road that is standing up well, we have a lot of places for our money, so we just have to let the thing go until it fails, and when we do that I don't think that is the place for stage construction because you have to take care of your first stage in order to put your second stage on successfully. If we could plan our work ahead so that we could put the second stage on at the proper time, it would be all right, but I doubt if there are very many highway departments that have the money and have things so organized that they can apply their second stage at the proper time. If you can't, I don't see how you can get the maximum benefit out of the second stage.

Mr. Gray:

I think all of us who have been highway officials know what the difficulties are in that respect. It is like a railroad would be if they were building their track and then somebody else told them how wide the trains were to be, how they were to run and how often they were to run. The marvelous thing is that we have done as well as we have. Mr. Gould lives in a neighboring state and favors stage construction, and I am going to ask him how he gets around that difficulty.

Mr. Gould: Iowa

Mr. Chairman, with your permission, I would like to go just a little further than what your comments imply, in order that I may a little better define and set out a little more definitely that subject which I am about to discuss. Naturally, in making any remarks I am confining them to conditions in my own state. Conditions in other states may not be the same.

First, it seems to me that we have to very definitely differentiate between the primary road system or state system and the secondary road system. They present, at least in our state, two distinct problems. In the first of those, the state system, we are perhaps well on our way to arriving at a reasonable solution. In regard to the secondary road system, I do not feel that we have even started yet. Now, with those explanatory remarks, I want to switch over to the subject of stage construction.

With regard to stage construction; of course, when I speak here, so far as I know I am setting forth the beliefs of the department and not my own necessarily. It is my thought, as presented in the paper, that we have surface treatment on stabilized bases. The surface treatment is advocated from the standpoint of resisting surface abrasion, and the base is to be designed to carry the load. Perhaps we haven't arrived at the point where we can successfully build such a road, but certainly it shouldn't be impossible. We are attempting to design our bases with that in mind.

When I speak of surface treatments, I am speaking even more definitely than that; I am speaking of the inverted penetration type of surface treatment in which the binder and aggregate are applied in a definitely prescribed manner and the construction operations of rolling and dragging are likewise carried on in such a manner that very dense surfaces well embedded with cover aggregate and sealed against surface moisture result. Stage construction in our state is favored because of the cost.

Preparation necessary to the second stage or third stage is not very high. At least that is what we are aiming for. The reason I am making that remark is that with a suitable base it should not be very high, consisting of repairing any unsatisfactory surfaces which may be the result of corrugating or rolling or ravelling, all of which can be taken care of by the maintenance forces in their regular operations without great expense. The second stage or third stage or whatever it may be, becomes merely another step in construction which is relatively of the same cost as the first stage of construction. Therefore, stage construction extends our expenditures over a period of years in which we have maintained our roads in good condition, and at the end of any definite period we have the road in better condition than we had when we started. While without stage construction over some definite period of time, let us say five years, the road has reached a stage where the need definitely will be reconstruction.

Now let me pass on from that to the secondary road system, which with us is now presenting a very definite and insistent problem. The present condition is that the state parks are receiving attention as to dust alleviation and the roads leading to the state parks will need the same attention by the counties. In our secondary road systems the highway department acts in an advisory capacity only as to construction work, but nevertheless we should definitely be in a position to lead and assist. This year we acted in an advisory capacity in securing some bituminous treatments in the more important parks. The demand naturally comes for attention to the roads leading up to those parks, some of which are dirt roads, some of which are surfaced, either with gravel or rock. If some other type of construction, both inside and outside the parks, is recommended, the matter of finances becomes a very important item, and there is where stage construction, so far as we can see at the present time, is the only solution because the funds are very limited, and when I say limited, I mean they are very definitely limited.

I don't believe we have given as yet the attention to this secondary road system that we should. I believe that we have to start, in our thinking, developing an entirely different class of treatment than that which we have been dealing with in our state system. That is where we have—well, of course, you haven't read the paper—but in the paper I make a brief comment that we have some theories, as yet untried and which will be more appropriately introduced after trial rather than at this time.

In closing, however, I want to make this remark that with regard to bituminous surfacing it seems to me that it is necessary that we keep not only an open mind but a seeking mind. I don't know that the solution to the secondary road problem lies in the bituminous field. If we are bearing in mind all our thinking along those lines, of course we will not find any other solution, but we should keep open-minded to where we can seek outside the field we are actually delving into at the present time, conscientiously, consistently, and persistently, and follow up until we can bring to the public a solution acceptable to them for their most perplexing road problem. I thank you .

Mr. Nuss:
Kansas

There seems to be a little confusion as to the definition of stage construction. What Mr.

Gould refers to on his primary roads is considered maintenance by us and is heartily endorsed. That isn't what I refer to as stage construction. I just want to bring that out. There is a little conflict as to the definition of stage construction.

Mr. Houk: Alabama — We conceive of stage construction in bituminous roads as first placing a solid, stable foundation course on the subgrade, one that you can depend upon to continue to remain stable, place the most economical surface that you can put on it, and then build that surface up in stages. It is really a stage construction surface, and I think that is the real opportunity in the low cost field. We have about 1,500 miles of inverted penetration, and I am happy to say that at this time our failures are very small in area and very few in number. They are limited to, I would say, three or four miles of actual length of patching. That is the total for the 1,500 miles and is much less than you see on the average western road mix in 40 or 50 miles.

If you have a stable base course and place a thin inverted penetration on top, you can come on back at intervals in the future, level it up, and give the public a new road at the cost of a few cents per square yard. You can improve it and you can widen it at the same time, progressively build it up to and with your traffic at a nominal cost. That is the objective. But the base course must be stable, and we believe that we have at last learned how to build stable bases, and we think we have built them.

Mr. Gray: I can assure you that Alabama has accomplished some fine works, and that it is a delight to ride over their system. Has anyone else any comments? I think that we really are all in favor of stage construction whether we call it by one name or another. But the point that Mr. Houk makes is a vital part of the whole question. There is no point in trying to improve a surface treatment to a road mix or a plant mix unless the road bed is properly constructed and properly drained so that it will stand up under all seasons of the year. If you haven't done that first, the rest will be only partly successful.

I like a development that started in the West and is sometimes called the "high line" grade. I think that is the best stabilization procedure that was ever invented. The road bed is raised up where it is away from the water, and then when the surface is waterproofed you are going to have a foundation on which to properly proceed to build up a heavier surface by stage construction methods.

In W. J. Leary's paper he has four questions, and they seem to me extremely pertinent. The first one was in regard to placing plant mix by the light mechanical spreader boxes or by a long wheel base drag. There is some difference of opinion as to the relative merits of doing the finishing operations by these methods. I am going to ask Mr. Zass of Arkansas if he will speak a moment or two to start off the discussion.

Mr. Zass: Arkansas

Mr. Chairman, we have not had a great deal of experience with laying plant mixes by machine methods. The results obtained, however, by such method have been entirely satisfactory. We have laid several hundred miles of road mix using blade graders as the spreading method, and we have obtained excellent results. I think that the finished line and contour of the blade spread road mix has been such as to place the finished work very close, if not equal, to any mechanical finishing method now in practice.

Mr. Gray:

Thank you, Mr. Zass. In connection with this blade grader method it has been suggested by a number of engineers that there may be certain benefits that result through spreading low viscosity mixtures with blade graders or even road mixers like blade mixers, which may not occur with more rapid methods; namely, a certain curing, a certain better adhesion of the bituminous materials to the aggregate particles. Whereas, if we use a higher viscosity asphaltic material in the road mix so that immediate spreading and compaction will take place, that process is somewhat delayed. I wonder if Minnesota has any definite opinions on the subject. Mr. Lang, you were pretty good this morning. I wonder if you would start the discussion.

Prof. Lang: Minnesota

Well, going back to the method of finishing, I rather feel that with a machine finish there is apt to be a little chatter action in riding that we don't get using the blades as maintainers. On the other point, Mr. Gray, I haven't anything definite that I can offer. I would be inclined to think that the point you brought up would be desirable over a longer time, but I really can't offer any help.

Mr. Gray:

Has anyone else a comment to make in that regard?

Mr. Hveem: California

We have spread most of ours, that is all our road mixes and practically all of our plant mixes, by a blade grader. We have used some of the new spreading machines, and, expressing a personal opinion, I have yet to see the finishing machine that would leave a road surface as smooth-riding as can be obtained on a good blade-finished job. But it is true that a blade finish is somewhat of a gambling procedure when a contractor is doing the surfacing. The contractor must have a man who is an artist with his hand on the blade controls. Without the said individual, even if the resident engineers in charge are experts, all the powers of persuasion and what else will not get the desired effect. It is a hard proceeding and one that is not entirely satisfactory, but the fact remains that blade finishing gives smoother and better riding surfaces than can be obtained any other way. In California there have been high hopes for machine finishers, but to date the best riding qualities have been achieved with the blade spread job.

In that connection, I would like to offer a personal comment, which I doubt will meet with general agreement from the engineers. In regard to the road profile, a line that will look well on paper and be satisfying to the engineering eye may actually be objectionable from the standpoint of smooth riding and producing a road that is pleasant to travel over. I believe that to the traveling public the gentle irregularities and undulations common to an earth road or bituminous surfacing finished with a grader tend to reduce chatter and road vibration in the car. A sensation of flying is much better achieved by a slight undulatory motion rather than by following a smooth plane on a road with a billiard table finish.

Mr. Gray: Well, I think there is a good deal to that last comment. It has another angle and that is in regard to unclassified excavation. In many areas the cut sections have been the most vulnerable parts of the surface due to the manner of cutting into the raw soil, when by rolling the grade a little more, excavation might have been decreased and a more stable road obtained.

I noticed in reading these papers the comments in regard to seal coats. I was rather surprised at Mr. Lockridge of Indiana in his comment on the desirability of deferred seal coating. I think I know what he had in mind, namely that with a certain liquefier type of cold mixes which are being widely used through his area a sufficient time should elapse for the liquefier to disappear before sealing the top. I think that is a matter of control of the time between mixing and placing. It is my own feeling that the seal coat should be put on within a few weeks and certainly before the winter season. I don't know whether that is generally agreed to, but I think many failures would be prevented if it were done.

Mr. Leary brought up the question as to whether or not to put aggregate on a seal coat. That is a new one to me. I have never seen a seal coat laid without at least some aggregate put on it. I wonder whether you get the full advantage of the seal coat. I am just asking that question, and I would like someone to comment.

Mr. Harsch: California — Nevada has used that method for sealing for the last several years, but they put this seal coat on immediately after laying and rolling the mix, about a tenth of a gallon of MC-2 seal coat, which enriches the top of the mix and helps it to seal over without destroying its non-skid properties. If they add that amount to the mix after it was well compacted under traffic, they might not get the absorption and it would result in a slick surface.

Mr. Nevitt: Missouri — I am sure we all see the effectiveness of that. That brings up a little announcement. There has been some work done on this by Professor Legault of Colorado State College, an analysis of seal coating which is now being published. It is being published in the form of an experimental bulletin and can be obtained by writing the college. He has collected data well adapted to the needs of many engineers. He brings out the results in use of various sealing materials and the need of varying amounts of cover material, and it may be some of your questions will be answered in his bulletin, which will be available in a few weeks. I think it is a very interesting one to the maintenance man, who I suggest should get the bulletin because of its very practical approach in its experiments on sealing, action of the residues, etc.

Prof. Lang: Minnesota

I would like to ask whether the type of aggregate governs whether you put it on or not, and whether such a type seal coat is slippery.

Mr. Harsch: California

No, it isn't. It is slippery for a couple of hours, but they put it on half width at a time as soon as the last of the job is completed, and it is the last operation. If the mix is porous enough, the road absorbs the seal almost completely. It can be done with a tenth of a gallon per square yard, grade MC-2.

Mr. Benson: Kansas

I have a few remarks which may be of interest. We, in Kansas, have been doing possibly different—I know it is interesting—research work with benzol extractions of mat. We have secured some very interesting results, some of which were given in the paper this morning.

Mr. Powers of Arizona mentioned briefly the penetration drops in asphalt. We have noted penetration drops in MC cutback materials varying from 73 to 132 points within 14 months' service. These materials were in dense type mats. This information was not brought out fully in Mr. Nuss' paper.

In connection with seal coating, we have noted, in connection with extractions one or two interesting results. A mat constructed in 1935 with a positive Oliensis MC-3 asphalt, was extracted at the end of 14 months. The penetration of the extracted asphalt in two samples was 19 and 17 respectively. The respective ductilities were 19.5 and 14.5 cm. This pavement was sealed after the samples were obtained, using two applications of MC-2, the first of about .1 gallon per square yard, and the second of .2 gallon per square yard, applied several months after the first application.

The mat at the time of the first extraction was very hard and brittle, and had cracked into small segments about six to eight inches in diameter over much of the surface. A second extraction, from the same area, six months after the last sealing gave asphalts with penetrations of 25 and 23, with respective ductilities of 67 and 12. The sealing material remaining on the surface, and the top ¼ to ⅜ inch of mat was removed from the sample before extraction. It is interesting to note that the sealing material succeeded in penetrating into the mat, livening up the dead asphalt originally present.

In regards to deferred sealing, some mats may preferably be sealed immediately after construction while others should be deferred. In connection with deferred sealing, one of our SC mats was constructed during the late fall of 1936, and sealed immediately. This mat failed by shoving and corrugating during the hot weather of July this year. The extractions on the unsealed mat agreed with the formula, after sealing it was considerably higher. In this instance, sealing should have been deferred. Some lean MC, and perhaps some SC mats, may be sealed immediately with good results.

Mr. Gray Any other comments on seal coating?

Mr. Zass:
Arkansas
I understand that there are generally two methods of procedure of laying road mix material after it has been processed. The first is that immediately after the mixing it is spread to its full width and throw open to traffic and maintained with a blade grader to keep it from sealing; in other words, aerated through spreading and open use. The other general method is to mix the material and keep it windrowed, moving and aerating the windrow daily for a number of days until a sufficient amount of volatile has evaporated, and spreading subsequent to such curing. Using either one of the two methods, wouldn't a difference arise as

to the effectiveness of seal coating placed either immediately or deferred?

Mr. Benson:
Kansas

If I understand the question correctly, it is one concerning MC cutback materials. It may be possible, in some cases, to seal immediately after construction, and no difficulty would be encountered as long as sufficient stability was retained by the mat, and the asphalt content was not made excessive by the penetration of the sealing material.

In an SC oil, the amount of volatile matter which would be lost by manipulation should be very small. The design of the mat in the first place should be based on the correct amount of oil for that particular aggregate. It is not intended that the asphaltic material shall change to any great extent, from a design viewpoint.

When the proper amount of oil is used, a critical condition may be encountered through immediate sealing by increasing the asphalt content. If the mat is very lean or dry, sealing with an MC or RC will correct a part of the deficiency. We have practiced this in the past and have secured satisfactory results.

Prof. Lang:
Minnesota

I understood you to say something this morning about applying MC-2 or MC-3 on old type hot mix pavement. Just what type is that? Was that seal coating?

Mr. Gray:

That was what you might call both a seal coating and corrective procedure. I at first thought of treating a hot mix surface, that is, a hard surface that is dried out, a medium curing product might not seem suitable because it would appear to leave a soft residue that might be slippery. The fact is, however, that the distillate in an MC-2 or MC-3 product is sufficiently small that when it has cut back the old surface you have a residue of around 150 to 185 penetration. The rate of application, of course, should be small, around .15 to .2 gallon. In other words, it should be scarcely more than a paint coat over the unbroken surface, a large portion of the material going down into the cracks and there mixing with the sand to make a tough, putty-like seal, with the cracks solid and stable. There is little danger of pushing or shoving. It is purely a healing action. We have found that it is often a much better method of procedure than using a rapid curing cutback. With a rapid curing product there is a tendency for the asphalt film to bridge over the crack rather than go down into it.

A slight modification of this procedure is used in seal coating the open graded mixtures, which are more prevalent in the East, through use of dry sand on the surface to first fill the voids. Approximately ten pounds of sand are spread over the surface and broomed. Then approximately a tenth of a gallon of MC-3 is applied as seal and a very light cover of sand put on top. That builds up a fine seal right at the surface which will not cause any trouble from shoving.

Frankly, in reading the papers prepared I think the average middle-westerner and easterner would get an erroneous impression as to procedure. In other words, practically all of the surfaces that they have been sealing are fairly water-tight already, and the application of further bituminous material without aggregate cover would appear to give a slippery top. I would like to have a little more discussion and know to what extent sealing is done, the character of the surface to which it is applied and the average amount of traffic that uses the road during the sealing period. Mr. McCoy, could you comment on that?

Mr. McCoy: Bureau of Public Roads

The use of RC-1 and MC-2 seal applications without cover is quite general in the West. It is usually done at the end of the job, and traffic is kept off for just a short time, long enough so that it can soak in. Occasionally they will speed up the use of the road for traffic by sanding it if needed. The quantity used varies from ⅛ gallon to 2/10 gallon per square yard. I think Wyoming has done more of this type of sealing than any other state, and I would like to ask Mr. Phillips or one of the other Wyoming men to describe what is used there.

Mr. Phillips: Wyoming

When I spoke of the MC-3 mixes here this morning, I mentioned that they appeared somewhat harsh. I probably don't make that quite clear. When I said that, I meant it comes out rather heavily grained, very much non-skid, and the type of job usually sealed with about .2 gallons of RC-2 with no cover material in most cases. That is the first application, placed from one week to three weeks after the job is finished up. In other words, the traffic forms a sort of glaze and kicks out some of the more or less loose material, from probably 50 to 200 mesh, that might be right on top, and takes it off the side of the road. We use the sweep before applying the seal coat so that our SC mix usually comes out smoother and apparently denser on top than does the MC mixes.

The seal on SC-3 mixes is RC-1 and that gives a sort of good strong penetration and doesn't lay on top. It just soaks in; it also enriches the top of the mat to a certain extent, just about ⅛ of an inch deep. We are using some sand cover, but we are usually controlled by the cost in construction operations. We usually place about from 3 to 5 miles of RC on one side of the mat at a time, depending on the traffic. The maximum amount of traffic would be from 2500 to 3000 cars per day. We would use one-way traffic on that length of the road and usually the length is set to bypass traffic in about 15 minutes. This RC-1, depending upon the density of the mat, dries in just a few hours, from 5 to 6 . In other words, we keep one-way traffic off it for one day and usually not that long. RC-2 takes a little longer than that sometimes, depending on air temperatures.

Mr. McCoy: California — I would like to ask Mr. Phillips if he has seen any signs of the sealed surface shoving under traffic. I haven't seen it, but the question was raised by Mr. Benson, who said that he has had some trouble with shoving when he used it.

Mr. Phillips: Wyoming — I have never seen it shove from using RC-1, but it occured to me the other day when I noticed that there was a distinct layer effect that it looked as though it could happen, though I haven't found any that has. This RC really sort of refluxes the top layer of the mat.

Mr. Benson: Kansas — In connection with some of the effects of sealing, it may be well to take into consideration some of the differences in weather conditions in the states to the north of us, and the conditions which we have in Kansas. Temperatures in Kansas are generally higher and of much longer duration during the summer months than are the temperatures and period of high temperatures in many of the northern states. These more severe conditions are, I believe, responsible in a large degree for the more critical behavior of our asphaltic materials and the construction employing them.

Mr. Harsch: California — The discussion would indicate that the eastern people think that seal coating is sealing a dense air-tight surface. In that case, a seal coat wouldn't be necessary, and when following such a seal with cover it would be considered a nonskid treatment in this part of the country. It is also a seal, but mineral aggregate takes care of the slipperiness.

Mr. Hveem: California

I might add that we have made one or two trials placing a seal coat on bituminous surfaces without additional screenings or cover. Where the road surface was of coarse texture there was no tendency to undue slipperiness. A seal coat without screenings would be undesirable where the surface was originally smooth. One advantage of placing seal coat without cover is the likelihood of providing a better seal. Moisture would be more likely to penetrate an oil membrane which was filled with rock particles extending through the seal. So far as California's experience is concerned, it is my own belief that in the majority of cases seal coating should be deferred as long as possible after construction.

Mr. Nevitt: Missouri

I don't believe that you can flatly say you can't seal after construction has elapsed. I believe that depends on the grade of material used. I believe Mr. Harsch is correct in that if they used an MC-2 they wouldn't get the penetration right away but later on they would. I believe thinner materials would go on the average job a year after construction, and I think the Wyoming boys will check me on that. They have sealed jobs two and three years after construction, not recently because they seal at the time of construction now, but in years back, provided they aren't these very rich jobs which were practically tight and slick, or these SC jobs which get tight and slick simply from the pounding of traffic. The average job can be sealed a year or two later, but the grade of material must be suited not merely to the surface textures, but also to the other conditions. The job does not have to be ravelling to permit sealing, and any one which needs it will take a seal coat of the proper type and viscosity which will decrease the voids to the desired extent.

Mr. Gray:

That is a most interesting discussion, and it brings out the desirability of comparing practices in different parts of the country to have a more complete understanding of differences that occur with different aggregates, climatic conditions, and the type of mixtures.

We have a number of other points here that are likely to produce a little discussion, and one is the matter of cracking in hot mix pavements. Mr. Powers in his paper brought out the critical point in the penetration of asphalt. I don't think that is the whole story, but I would further draw attention to the fact of the particular condition of climate and temperature in which behavior occurred as described. Mr. Skarin of Edmonton is here, and he asked me a question about cracking during recess and I am going to ask him if he will just make a statement of the conditions as he has found them in his city, and then perhaps we can have some discussion on behavior and possible remedies.

Mr. Skarin: Alberta

I am connected with the Crown Paving Company, a contracting concern that has built pavements since 1905. In the early days we used to be able to lay sheet asphalt and asphalt concrete without many cracks occurring. Of recent years it seems next to impossible to lay those pavements without cracks, using the same methods and material, the only change being that we now have better equipment. I have noticed pavements laid 20 and 25 years ago, and feel rather ashamed to come back to pavements laid four or five years ago and see how much more they are cracked than those of 25 years ago. And we are at a loss to really trace the trouble.

We think that there has been a gradual lowering of the asphaltic quality in asphalt, but materials men are not ready to admit this, and the tests of the asphalts have not shown any appreciable difference. So where is the trouble? We used the ordinary D grade paving asphalt, penetration of about 65 to 75 in the early days, and we stayed like that until just recently when we changed to 85, and the cracking was reduced perhaps more than 50 percent by that change. But the fact remains that when we used 65 to 75 penetration we built pavements that have less cracks after 25 years than pavements with the same penetration built recently. I now would like to have some ideas about this, and I am sure you gentlemen will help us. Our climate is about like Montana, except that it does not get as hot in the summer time and is a little colder in the winter time.

Mr. Benson: Kansas

I would like very much to know if Mr. Skarin has had access to any analysis of the asphalt which is present in the pavement. What I have in mind is the work of Professor Rader, as reported in the proceedings of the Association of Asphalt Paving Technologists, 1936 and January 1937 meetings. In this work several pavements such as you describe were analyzed, and if I remember correctly, those pavements in which the most cracking occurred were those of a low penetration. The softer asphalts, as a rule, did not crack as badly. I am not sure whether or not you mentioned the length of time required for the cracking to take place.

Mr. Skarin: Alberta

I am glad you raised that point. In the pavements laid recently, say 4 or 5 years ago, there appears to be a gradual hardening, such as we have heard mentioned here today. I am sure the penetration if taken now from the pavement would be less than 25. I cannot verify that by tests, but we had tests made of the pavement laid 25 years ago. Mr. Field was then in Calgary, and he often made tests for us, and I cannot recall what the penetration was that those tests showed, but I would judge that it remained very much the same as when laid, and now it does not.

Mr. Benson: Kansas

I would like to make a few comments concerning our investigation of hardening and brittleness, with ensuing cracking in bituminous mat surfaces. The investigation was made on a number of MC and SC mats, and two sheet asphalt pavements. The sheet asphalt pavements were laid in 1911 and 1917, respectively. The first pavement was in excellent condition and no maintenance was visible. This material, on extraction, had an asphalt of 21 penetration and 150 + ductility. The original penetration was 40, so that the drop in penetration over 26 years was only 19 points.

The second sheet asphalt pavement was very badly cracked, and large areas required replacement after the winter of 1936-1937. A sample of the pavement yielded an asphalt of 11 penetration, 4 cm. ductility. The condition of the pavement is reflected in the penetration—ductility characteristics of the extracted material.

The mats constructed of MC cutback material were very hard, some had cracked badly. The 1936 extractions on eight 1935 construction porjects, in which thirteen extractions were run, gave asphalts from 45 penetration in two samples to as low as 13 penetration in one sample. The other penetrations varied between these two points. The age of the materials extracted was from 10 to 14 months. Two materials were negative Oliensis, with extraction residue penetrations of 40 and 37, ductilities of 27 and 80, respectively, with 10 months' service. Materials extracted after three months of winter service showed no loss of penetration or ductility. These cutbacks originally had penetrations of from 109 to 151. The highest penetration, that of 151, dropped to 19 at the end of 12 months.

The results of 1937 extractions showed that the penetrations dropped less during the second year, the 45 penetration mats gave 28 and 25 penetration asphalts, the remainder dropping from 10 to 4 points in penetration.

Some SC mats constructed in 1930 and 1931, some of which are as yet unsealed and have given excellent service, yielded liquid asphaltic materials of from 470 to 5750 seconds, Saybolt Furol 140° F.

From the results of these extractions and the service records of the earlier SC type mats, it is believed the MC cutback material suffers excessive hardening, and that SC oils would prove more serviceable. If there is any comment on the method we used for the extractions, I shall be glad to answer.

Mr. Houk: Alabama — I didn't think there was any argument to be brought up on the hardening of asphalt. It is hard to find any hot mix pavement 10 years old that hasn't cracked and become embrittled. That is the reason we have abandoned hot mixes, and that is why we favor the thin inverted penetration or armor coats.

Mr. McKesson: California — I would like to ask the gentleman who told us of the cracked pavement if there has been any difference in the source of asphalt during these years and secondly if the present practice of preparing your mixes involves different temperatures than you used to operate with.

Mr. Skarin: Alberta — In the early days our asphalt was made from California crude oils. To a certain extent we are using them now as well, but we are securing our asphalt through the Imperial Oil, and probably use more mid-continental oil then we formerly used. Our method of preparing mixes is very much the same. Only in the early days we had kettles and fires under them; now, of course, we use tanks with steam heated coils.

That really should help matters. Our heating capacity is rather improved, and that would tend to keep the aggregate a little warmer.

Prof. Lang: Minnesota

We have been doing some work in our laboratory recently. We have a little pug mixer in the laboratory and it mixes up mixes of about 2,000 grams of Ottawa Sand at a temperature of 180 degrees F.

We have asphalts of 85-100 penetration from 23 different sources. We have found that on the recovering of asphalts after mixing and allowing to stand for some time, that the penetration of the recovered asphalt carried from somewhere around 15 to somewhere around 60. I might add that one of the best asphalts as far as change in penetration is concerned came from the mid-continent field.

Mr. Hveem: California

I would like to add a little more on this point. California has not as yet undertaken much laboratory work in the matter of hardening of asphalts. We have not made many tests on asphalts from the old pavement. However, there seems to be enough evidence accumulated elsewhere to establish the fact that asphalts do tend to harden and become brittle to a detrimental degree. In order to determine whether pavements show less cracking if softer asphalts are used, experimental sections were recently constructed using various grades of asphalt ranging from 56 to more than 200 penetration, the high penetration being commonly classed as 90-95 road oil. The experimental work done was a high type hot mixture, with as little change as possible in the percentages of asphalt or the grading of aggregates. The mixtures were all placed without any difference in the usual spreading or rolling equipment. Plant mixing temperatures were reduced from 300° F. with the 50-60 penetration asphalt to 200° F. with the 174-250 penetration "E" grade. In order to get some additional light on what changes might take place during mixing, we made a set of experimental mixtures with different grades of asphalt. The batches were held in the pug mill mixer and discharged at various intervals of time, at 45 seconds, 1 minute, 1½ minutes, 3 minutes, and 5 minutes, to determine whether the mixing periods would affect penetration of the asphalt. Examination of the mixtures is not yet complete, but it appears that the asphalt extracted from the mixtures had dropped to about 40% of the original penetration. These figures are subject to further checks, and there are some discrepancies to be reconciled. However, there is no question that considerable change took place in the comparatively brief period in the pug mill.

Mr. Nevitt: Missouri

You stressed some time back the importance of evaluating the factors in the picture. I think that is extremely important. Here I am thinking perhaps that it is more important in MC work than in hot mixed pavements because in our territory we have so little hot mix work. I do not believe you can compare reductions in penetration of residues and changes in viscosity or any other characteristics on a mix that has been in service without also bringing into the picture the comparative mix richness, the type of aggregate and the type of grading. I know from my own experience many years ago in this territory, you can take a very thin SC, put it in a lean mat, and in a year it will turn a nice brown or light gray, and practically disappear. If you will extract it before it has gone to this limit, you will find your mat showing a decreased oil content; also you will find a greatly increased viscosity, and even the oil reduced to the penetration of an asphalt

It is the same way in the case of MC's. There is undoubtedly reduction but the degree of reduction is greatly affected by the richness of the mat, by the absorptive characteristics of the aggregate, and by the grading of the aggregate. I therefore believe that any data which refers to the reduction of the penetration is incomplete without bringing these into the picture. The reason I emphasize the amount of MC is that in starting out to use MC material it is a usual fact that the jobs are made too lean. We know we have some volatiles which will be lost, and in addition, especially where the MC has been very lean, there will be a further loss of the non-asphaltic fraction due to adsorption. It has taken some experience to find out the large effect of this particular feature. I think it is very important to bring such data into the picture before any conclusions are too strongly drawn.

Mr. Benson: Kansas

I am glad that you brought up the point in regard to the richness of the mat. In conducting our investigation we took into account as many factors as possible, including void content, the gradation of the aggregates and fines, the gaseous permeability of the mat, and the asphalt content. Other tests have also been used. We have attempted in many ways to determine the cause of the rapid hardening of MC materials.

The void content of the mats examined varied from 0.09% to 14.8%. In this connection it is rather interesting to note that, of the two highest penetrations secured from extracted materials, voids of 14.8 and 7.45% were obtained. There does not appear to be a necessary correlation of rate of hardening and voids.

One mat had an asphalt content sufficient to cause corrugating and shoving under traffic, the void content was 0.09%, the original penetration 109, the extracted penetration at the end of 10 months service 32. The richness of the mat does not appear to be a critical factor. Why, we do not know.

Tests for gaseous permeability were also run. This was performed by sealing a glass tube of 1¾ inch diameter over a specimen of mat, as nearly undisturbed as possible, and forcing air through the specimen with pressure equivalent to 6 inches of water. The permeabilities varied from zero in the 21 penetration sheet asphalt pavement, to 307 cc/sq. in./min. in a mat with 10.99% voids. Here again, little correlation was evident in the MC mat between permeability and rate of hardening.

The voids and gaseous permeability in those SC mats which yielded liquid asphalt after years of service, indicates that the aggregate, and particularly the very fine material, may be critical factor in determining the aging and hardening of the asphaltic material, rather than a strict correlation with voids or film thickness.

Important investigations on the effect of very fine mineral matter on liquid asphalts have been made by Mr. Traxler of the Barber Company, Mr. Bollen of Nebraska, and others. While these investigations have given an insight into physical alterations of the properties of the materials, much work remains to be done to determine the protective effect from a weathering viewpoint of the fine material on the asphalt.

The protective effect of asphaltic material on the aggregates and its function in binding together the constituents of the system has been highly stressed, the action of aggregate and the system towards protecting the asphaltic material from hardening, aging and weathering has perhaps not been stressed as highly as the importance of the problem warrants. It appears that one of our greatest problems is to maintain the asphaltic material in a serviceable condition, in our mats and pavements. That problem should be borne in mind, both in the design and construction of our mats and pavements.

Mr. Nevitt: Missouri

This is a rather involved technical matter. However, my concept of what affects this hardening, particularly in the MC, is not so much either the gaseous penetration or the richness condition indicated by the void content. Richness is really a matter of film thickness, I believe; the void content is more a function of the grading. The point about absorption is that if you take a film and absorb a definite amount of oil from it, the change in the thickness of the film is the same regardless of the original amount of oil used, but the change in viscosity or consistency for this constant amount absorbed is very greatly affected by the original film thickness; that is, you greatly increase the consistency range as you thin down the applied film. Hence your viscosity change in the thicker film is much less. So that I think that film thickness is the factor that takes on importance rather than the void content. The whole thing is rather complicated. I want to say, along the same line, that if you take from an MC a small amount of distillate, you get an entirely different consistency change than from a soft asphalt or road oil; that is, you may get a relatively larger change in consistency than you would from SC. My opinion is that this is a rather complex thing which must be analyzed very carefully before conclusions can be too strongly drawn.

Mr. Benson: Kansas

If Mr. Nevitt could tell us how to get thicker films without changing the types of asphaltic oil we are now using, it may be possible to secure better results. If you get into thicker films, changes in both the asphaltic material and aggregate may be necessary.

The advisability of making these changes is questionable in view of the excellent service rendered by some SC type materials in dense type mats.

Mr. Gray: We could go on with this discussion for a considerable period but time is drawing on, and so as a temporary conclusion possibly a few comments in regard to some of the traffic and plant changes which have occurred but which have not been taken into full consideration may be helpful. I recall sheet asphalt construction of twenty to thirty years ago and I compare the procedure then with the procedure today. We do of course have asphalt from a greater number of sources than we did then. However, we have the same phenomenon of cracking in pavements using asphalts which are identical with those of years ago and that are refined in the same manner. Of course not all asphalts are refined in the same way, but we have carried on tests with asphalts which were refined in the same manner and yet we have cracking in pavements made today using these asphalts which was not previously apparent. It is believed that this cracking is due more to unconsidered new factors rather than to fundamental changes in the asphalt cement itself.

Some of the factors are these:

1. Twenty years ago or more it was a general rule to flux asphalt cement during its use. The amount of fluxing was sometimes small but it was continuously added. Now we know the value of highly ductile fluxes, and that even a small percentage might affect the ductile character of the finished mix. In contrast today we use a straight refined asphalt cement of a given penetration and without fluxing as a rule, so that the softer ends are not continually introduced as was formerly the case.

2. Another factor which had a similar effect to the foregoing was the constant dripping of oil from the earlier automobiles and trucks so that oil was streaked out over the surface, thus continually softening and livening the asphalt

cement in the pavement. That effect is today non-existent on most pavements. However, we have observed in some of the large cities the difference in cracking on streets made of identically the same type mixture, but in one instance where truck traffic was particularly heavy and with a majority of old trucks and where cracking was decidedly less than on the street having the more modern vehicles.

3. Improved plant equipment provides for the substitution of oil burners in place of the old coal burners, and while this provides for more uniform heating, I believe that it results in somewhat higher aggregate temperatures, with the result that there is a tendency for the asphalt to be more hardened under present plant conditions than occurred years ago. I do not think that as a rule this change has been fully appreciated and it may easily account for hardening of as much as ten points of penetration.

4. The reaction of traffic on pavements today is just the reverse of years ago. Steel-tired traffic and slow-moving, hard-rubber-tired traffic had a tendency to constantly anneal and knead the pavement surface, resulting in both a densification of the surface and also a constant relivening of the asphalt cement. Under balloon tires there is a tendency to tear up the pavement and a constant suction. Consequently, the pavement tends to remain as dry and in the same textural condition as when placed. If there is any tendency it is one of ravel and not of becoming more fat.

5. With the development of the several stability machines and the finding that high dust content made for high stabilities, there was a universal tendency to increase the percentage of dust unduly. While such practice produced high stability, it also tended to produce a more

brittle pavement, which, coupled with all of the foregoing changes, made the pavement more susceptible to contraction, particularly at low temperatures. It is suggested that high dust contents are neither necessary nor desired, and that only enough dust should be used to produce the **minimum** stability required for a given traffic.

6. Asphalt pavements are placed on a variety of bases, the usual city design being either a Portland cement concrete or an asphaltic concrete. There has been a tendency in recent years to increase the richness of Portland cement concrete base, and which is believed to be a wrong practice. Years ago this type of base was usually 1:3:6 or learner and while the base cracked, these cracks were small and did not reflect through to the surface. With a 1:2:4 mix or richer, the cracks may be fewer but they are also bigger and are apt to reflect through to the surface of the pavement.

I have mentioned these several items for further study and I believe that if we will analyze all the studies that have been made, we will be a good deal further along the road. One item may be of interest. It is along the line of Mr. Nevitt's comments. Asphalt is akin to class in some of its characteristics. Glass placed in a window subjected to light over a long period of years changes in its molecular structure, becomes increasingly brittle. Thin asphalt films do the same thing. If you take an old piece of glass that is, say, 100 years old, it will be very, very brittle. But if you melt it down again it will gain back nearly its original degree of elasticity. If you take an old asphalt mix and remelt it, you will find that the cement may have increased in penetration.

That brings up the question: What are we going to do about it? And is it such a serious matter? This leads to a discussion of maintenance methods, and I don't intend to encroach upon what Mr. Houk will present tomorrow. However, it is an entirely practical procedure, in order to preserve the asphalt in its most desirable condition, to plan for very light seal coats at such intervals as may be found best suited to reliven the surface. I see nothing wrong with surface treating an asphaltic concrete or sheet asphalt at least at 10-year intervals. Just because we have some pavements which have lasted 20 or 25 years doesn't mean that they will go 25 years in the future under new traffic conditions, and we should readjust our technique with a view to lowest annual cost of the paving. If we must spend an increased sum of money initially in order to get five years more of life without any treatment than would be the case of making one or two light surface treatments in the intervals, it doesn't seem to me to be good judgment.

One further question was asked during recess and I promised to bring it up although we are getting short of time—and that is the matter of resurfacing wooden bridge floors built of creosoted timber. I believe several engineers wanted to know if anybody had had experience in this regard. As you may know, creosote is an excellent cutback distillate for asphalt cement. Such cutbacks are widely used in England. Creosote as a cutback has high solvent powers. Consequently, if you have treated timber that is new and you put an asphalt mixture on it, there may be cutback action between the asphalt cement and the creosote timber. Therefore, it is desirable to place a creosote timber floor under traffic for some weeks prior to placing any substantial depth of surface such as a hot mix. However, taking into account the cutback action of the creosote, it is possible to make very thin surface treatments, (less than one-half inch in thickness) with mineral aggregate so that even though cutting action does take place, no pushing or shoving will occur. A large amount of such work is done through the East where there are many old steel bridges which have been refloored with double wooden plank.

If there is no further discussion, as our time is up, we will adjourn.

Papers Prepared

on

Developments in Practical Design and Construction of Bituminous Surfaces

for

The Montana National Bituminous Conference

Developments in Practical Design and Construction of Bituminous Pavements

By

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Prior to 1934 the entire mileage of bituminous surfacing in Alabama consisted of Sheet Asphalt, Asphaltic Limerock, or modified Topeka on bituminous or "black base" Portland cement concrete base, with the exception of a few miles of bituminous penetration macadam. Prior to this time nearly all pavements were laid directly on whatever subgrade soil was encountered in the grading operations.

In 1931 the engineers of the Department were confronted with the fact that much of the existing concrete pavement six to eight years old was seriously impaired and fast deteriorating. To forestall this a reinforced section was used after 1931 and special treatment was given bad soils. This operation disclosed to the Department's Engineers the necessity and value of subgrade treatment even for the highest of the so-called high-type pavements and that a more economical and suitable type of pavement must be developed if the demands for surfaced roads were to be even partially met.

Several types of bituminous surfacing were tried, namely; open type road-mix, closed type road-mix, open plant mix, surface treatment, with considerable loss on several projects due to lack of understanding of proper selection of materials for the base or foundation course, but these failures due to the neglect of the fundamentals of design proved of distinctive educational value.

It was soon found that more money should be spent in the selection of natural occurring materials and their stabilization, that would produce good base courses and consequently a better and less expensive pavement, a pavement that will fill immediate traffic needs and will always have a salvage value approximating its first cost, if and when it is necessary or desirable later to place another type of pavement. This salvage value arises from the fact that no expense is incurred in low cost base construction except what is necessary in sound design and construction practice of any expensive so-called higher type of pavement.

To meet the demands for mileage, the Department strove to select and develop an economical type of bituminous surfacing and construction methods which can be varied with materials in the different sections of the State and to suit specific traffic requirements. Bituminous surface treatment (inverted penetration macadam) has proven most successful.

This type of stage construction consists of a well-drained grade and well compacted subgrade, a base course of selected stable natural material or combination of natural materials from 6 to 8 inches compacted thickness and from 22 to 36 feet wide, shoulders of selected open granular material and a surface from 18 to 22 feet wide, consisting of a one-inch armor course composed of bitumen and aggregate.

Soil investigations are made before and during grading operations to ascertain the suitability of material for the roadbed. Where practicable, unsatisfactory material is rejected or deposited beyond the shoulders and replaced with that of good bearing value. When it is impracticable to replace all the unsatisfactory material, the sections of subgrade in which it occurs are reinforced either by stabilizer or subgrade treatment to the degree necessary to provide a subgrade of reasonable bearing value.

Material surveys are made before construction work begins on all projects. Suitable materials are located, analyzed as to suitability for base courses, and best and most economical local material used. The thickness of the base course depends upon the character of the subgrade, the quality of the material available and the traffic expected. The behavior of the type bituminous surface used is already known since sufficient mileage has already been constructed so that the cost can be almost exactly determined, the only variables being the slight fluctuation in prices of bitumen. The bituminous surfacing is placed directly upon the compacted and well shaped base course.

The surface course construction consists of first a bituminous prime or tack course, spread directly upon the base course, usually amount to .3 of a gallon of bitumen per square yard extending one foot beyond the edges of the width surfaced, second a bituminous course of either AC 9, 10, 11, or TH 2 or 3 grade of tar, uniformly spread at approximately .45 of a gallon per square yard directly upon the dry prime or tack course. Third, the aggregate course consists of well graded gravel, crushed stone, or slag, all passing a 1¼-inch sieve and 90 per cent retained on a ½-inch sieve, and is immediately spread directly upon the hot bituminous course at the rate of approximately 45 to 55 pounds depending upon the specific gravity of the aggregate per square yard. It is then carefully broomed into place to fill all voids and rolled lightly to embed it in the hot bitumen. After this, the road is opened to light slow moving traffic until the aggregate is firmly embedded and set.

If additional thickness or an improved wearing surface is desired, it can be sealed by one of the following three methods, (1) hot application (same as first course excepting .3 of a gallon of bitumen and aggregate grading from ⅝ of an inch to a No. 16 sieve is used), (2) drag operation or (3) one of the various types of cold mixes.

The construction of this road type is very simple and economical.

The equipment necessary for surface construction is a broom with blower attachment, a distributor for bitumen. trucks with detachable spreader boxes for spreading aggregates and a five-ton roller for embedding the aggregate into the bitumen.

This type of surfacing is far past the experimental stage and has become a proven type giving universally satisfactory results in the Southeastern States, but we are constantly striving to improve subgrade stability, build better bases and improve the riding quality of the surface to the end that no maintenance expenditures will be necessary until worn to the point when retreading is necessary. Each retreading properly done builds up the thickness of the mat and gives the road user a new pavement smoother and better than the preceding one.

Hardening of Asphaltic Cement in Asphaltic Concrete Pavements

By

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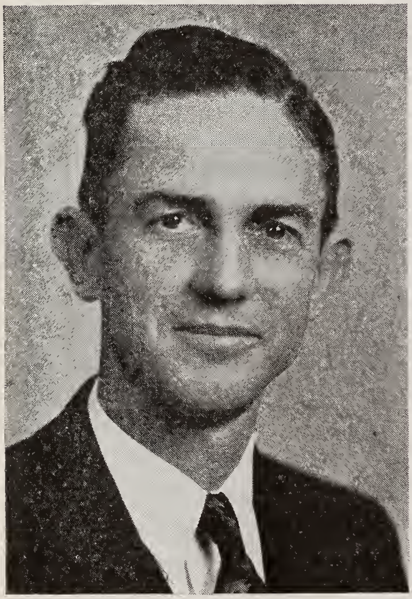

While this conference is primarily concerned with low cost type of construction, I believe the subject of this paper can properly come before this group.

Development of cracks and the increased roughness of the riding surface resulting therefrom, led us to investigate the properties of asphalt in some of the older pavements in this State. Samples were taken from projects built by the Arizona State Highway Department, and from the streets of Phoenix and Tucson.

While all the records of the original pavements are not available, enough were obtained to give a fair idea of the extent to which the asphalt had hardened.

All asphalts were extracted from the mixes, using the method of Gene Abson*. Before utilizing this method however, asphalts of known composition were dissolved and recovered. The recovered asphalt checked the original very closely. All solvent (benzol) carrying the dissolved asphalt from samples of pavement were supercentrifuged prior to recovery of the asphalt; in every case the supercentrifuge was allowed to attain a speed above 40,000 r.p.m. before introducing the benzol asphalt mixture. This procedure eliminated practically all the fine dust that had been forced thru the filter from the bowl of the Dulin Rotarex Extractor leaving no contaminants which might affect the penetration of the recovered asphalt.

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* = Method and apparatus for the Recovery of Asphalt, Gene Abson, A. S. T. M. Proceedings, Vol. 33, 1933, page 704.

The following table gives the results on twelve different samples:

No.	Date Laid	Location	Original Penetration at 77°F.	Determinations on Extracted Asphalt					Type and Condition
				Penetration 77°F	115°F	Softening point R&B	Ductility 77°F	115°F	
1	1934	Phoenix	56	12	76	148	12	....	4″ asphaltic concrete, Excellent
2	1921	Phoenix	39-41	6	28	168	0	....	6″ Warrenite Badly cracked
3	....	Phoenix	....	16	92	143	100+	....	Warrenite, good except asphalt is flowing out of mix
4	....	Phoenix	....	12	57	152	10	....	Warrenite, good except asphalt is flowing out of mix
5	....	Phoenix	....	5½	20½	170	0	....	Warrenite Badly cracked
6	....	Phoenix	....	10	53	153	5	....	Warrenite Badly cracked
7	1923	Florence Junction	41-58	3	11	196	0	15	2″ Warrenite on sand-clay base, badly cracked
8	1923	Tucson	59	7	35	179	0	100+	Excellent
9	1920	Tucson	52	2½	5½	218	0	0	Willite pavement Badly cracked
10	1914	Tucson	....	15	63	152	15	100+	1½″ Warrenite on 4″ cement concrete base Excellent
11	....	Tempe	....	4	13	187	0	7	1½″ Warrenite on 4″ cement concrete base Badly cracked
12	1936	Phoenix	57	19	142	138	60+	....	1½″ asphaltic concrete over old Warrenite Excellent

It is apparent from these results that loss in penetration is accompanied by a decrease in ductility, and an increase in the melting point.

In order to get some insight into the effect that temperature of mixing might have had on hardening, we obtained samples of mix from a plant operating on one of our jobs and found that over the range 265°F. to 305°F. the penetrations of the extracted asphalt varied little if any from that which would normally be expected when mixes are kept in sealed containers. (Sample 12 represents material from pavement in May, 1937.)

Indications of the rate of hardening was noted on a recently laid asphaltic concrete job in the City of Phoenix. A short section on a thru truck route was laid using 109 penetration asphalt. We obtained mixes and stored them in air-tight containers and kept them in the laboratory to be extracted from time to time with the following results to date:

Age Days	Penetration 77°F.	Age Days	Penetration 77°F.
1	95	28	78
4	91	56	72
8	88	106	63.5
19	81		

It is proposed to hold these mixes until such time as they are exhausted and extract them from time to time. It is hoped in this way that we may be able to follow the hardening process, and also watch the action of the pavement.

From this data we believe that asphalts of softer grades can be successfully used, and that they will serve equally as well as the harder grades. Certainly if the usual 40-60 range of asphalts are considered to be satisfactory on the basis that they remain in that state, but which we feel they do not for any length of time, there would be no objection to starting with a softer asphalt and attaining that goal at a later date.

Construction of Bituminous Surfaces in Minnesota

By

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Bituminous Materials have been used in the treatment of road surfaces in Minnesota since 1924. The first treatments were experimental in nature and the mileage small, but the quantities used have gradually increased so that for several years a substantial mileage has been placed annually. Until 1932, the bituminous surfacing had been carried on as a part of the maintenance program and although the Maintenance Division still carries on a rather extensive bituminous program the number of projects contracted for by the Construction Division has gradually increased.

The subject of soil surveys and base design for bituminous surfaces in Minnesota has been covered in another paper. Suffice it to say that detailed soil surveys are made by our soil engineers to provide adequate base support for proposed bituminous surfaces. This has resulted in the obtaining of bituminous surfaces more certain of success. This design of satisfactory and adequate base is consistent with the present day realization that provisions for such base support are both desirable and necessary for successful bituminous surfaces.

The present practice in Minnesota provides for the placing of a clay-stabilized gravel base course, the thickness being dependent upon the existing base conditions. Previous practice permitted the placing of bituminous surfaces on partially stabilized gravel bases and sometimes loosely bonded gravel bases. In such cases provision was made for the mixing of bituminous material with the upper portion of the gravel base, but not always with the degree of success that was hoped for. Localized breaks resulting from looseness of gravel below the matter portion occured which were very unsatisfactory and difficult to repair. Such breaks were frequently reflected in succeeding surfacing courses. The providing of a stabilized gravel base of adequate thickness yields a firm foundation for the mixing operations and the bituminous mat.

The bituminous surfaces built in Minnesota have consisted of both the road-mix and plant mix types. Because of the availability of good gravel throughout the state, this material has been generally used, although on a number of highways carrying a high volume of heavy loaded traffic and where crushed rock is available, the latter has been specified as aggregate. Where the projects have been of sufficient length to justify the cost of bringing in a plant and when the base has been such as to assure adequate foundation and reasonably permanent smoothness, the plant mix types have been specified. On relatively new bases it has been thought preferable to place a road mix surface of lower cost which would adequately serve the traffic for some time until the base had reached its practical ultimate compaction after which the higher type plant mix surface would be placed. This general procedure has proven quite satisfactory.

The early bituminous treatments in Minnesota consisted of what were known as ''blotter'' type treatments or variations thereof. In this treatment, a prime coat was applied, which after absorption by the base was followed by a second application which was immediately covered with gravel of one inch maximum size. The bituminous material was permitted to be ''blotted up'' by the gravel while light blading was carried on to maintain a smooth surface.

The present procedure in the construction of road-mix surfaces involves the placing of one or two courses in which the gravel for each course is spread over the surface of the road, followed by an application of bituminous material at a specified rate after which the gravel and bituminous materials are mixed by means of blade graders or multiple-blade maintainers until a uniform mixture is obtained, following which the mixture is spread to the desired width and section. Rolling of each course with a self-propelled roller is required. If the surface is laid in one course a prime coat is required, whereas if laid in two courses it is usually specified but may be omitted at the discretion of the engineer. It is generally required as it is felt that the prime coat is desirable.

The bituminous materials used by the construction division have consisted almost entirely of cut-back asphalt and cold application tars for the road-mix projects. In the case of asphaltic materials it has been felt that cut-back asphalts of the medium curing type were preferable to the slow curing oils because of the greater resultant stability of the bituminous mat and with less danger of exceeding the critical bitumen content. The Maintenance Division, however, uses a substantial quantity of slow curing oils each year for use on roads of questionable base support so that they can be subsequently scarified and remixed following their break-up.

The specifications for the gravel aggregate for the road-mix type are as follows:

"The mineral aggregate shall consist of gravel composed of sound durable rock. When tested by means of laboratory sieves, it shall conform to the following gradation:

Passing	¾ inch sieve (square opening)	100%
"	⅝ " " " "	95-100%
"	⅜ " " " "	65- 95%
"	#10 Sieve (U. S. Standard)	25- 60%
"	#40 " " "	5- 35%
"	#200 " " "	0- 5%

The total clay content (material finer than 0.005 mm.) shall not exceed two (2) per cent by weight."

The prime coat, consisting of cut-back asphalt MC-1 or a light grade of cold application tar is applied at the rate of 0.1 to 0.3 gallons per square yard, with .15 to .20 gal. per square yard being the usual rate for clay-stabilized gravel bases. If the surface is to consist of one course, such course is usually placed at the rate of 100 pounds of gravel per square yard, with the bituminous material applied at the rate of 0.55 to 0.75 gal.

per square yard. If cut-back asphalt is used the grade is usually MC-2. If two courses are to be laid the first course is usually placed at the rate of 80 pounds per square yard and is designed to eliminate irregularities in the base. The second course is usually 100 pounds per square yard as described above.

Two types of seal coats have been specified the past season. The first consists of an application of 0.10 to 0.15 gal. of bituminous material per square yard and is not covered with seal coat aggregate. Such seal coats appear to be quite satisfactory, particularly where it is anticipated that additional bituminous surfacing will be placed following the attainment of ultimate compaction by the stabilized base. The second type of seal coat employed consists of the application of 0.2 to 0.3 gal. of bituminous material and the covering of the same with from 10 to 25 pounds of coarse sand per square yard.

The road-mix surfaces described above have proven quite satisfactory in that they yield durable, smooth riding surfaces of adequate stability.

A considerable mileage of plant-mixed surfaces have been built employing for the most part gravel aggregate. Our plant mix surfaces are placed on existing bituminous surfaces or on stabilized gravel bases upon which is first placed a bituminous road mix leveling course. Irregularities in contour or crown in existing bituminous surfaces or clay-stabilized gravel bases are eliminated by the placing of leveling courses resulting in the obtaining of a plant-mixed bituminous surface of uniform thickness and of the desired crown and contour.

The bituminous materials used with gravel aggregate have consisted of cut-back asphalt MC-4, hot application tar TH-3 and asphaltic oil with powdered asphalt.

The specifications for the gravel aggregate are as follows:

(1) Total percent passing

¾″ Sieve	100
⅝″ ”	95-100
⅜″ ”	65- 95
#4 ”	45- 70
#10 ”	35- 45
#40 ”	5- 25
#200 ”	0- 5

(2) The portion retained on the No. 4 Sieve shall contain at least thirty (30) per cent of crushed particles, and shall pass a Los Angeles Rattler test in which the maximum loss shall not exceed forty-two (42) per cent by weight, in addition, the aggregate shall not contain more than fifteen (15) per cent by weight of particles which when selected by hand and tested. show a loss in excess of fifty-five (55) per cent by weight.

(3) The total aggregate shall not contain more than three (3) per cent by weight of shale or other unsatisfactory materials.

(4) The total clay content (material finer than 0.005 mm.) shall not exceed two (2) per cent by weight.''

In the case of cut-back asphalts, the proportions specified are as follows:

Mineral Aggregate	95.2 to 95.6%
Cut-back Asphalt	4.4 to 4.8%

The maximum temperature of the aggregate at time of mixing is limited to 175° F. and the minimum mixing time to 50 seconds. It is to be noted that no filler material is added to the mixture. These mixtures have proven very satisfactory with no evidence of instability. It is felt that the use of cut-back asphalt or hot application tar with no filler material added results in a mixture of adequate stability and is less critical to bitumen content than mixtures in which slow-curing oils are used together with added mineral filler. Up to the present time the plant mixed gravel mixtures have not been specified with a seal coat. Our new specifications provide for the inclusion of a seal coat.

A number of projects have been constructed using crushed stone as aggregate where the traffic has been heavy both in volume and in weight and the crushed stone available. Such surfaces have been laid on existing bituminous surfaces or a bituminous road-mixed leveling course has been placed prior to the construction of the plant-mixed surface. These surfaces are laid in two courses (a binder and a wearing course), with the binder course being laid at the rate of 140 pounds per square yard and the wearing course at the rate of 60 pounds per square yard. The gradings of the aggregate specified for each course are as follows:

Binder Course

Passing	1¼″	Sieve	100%
”	1 ″	”	95-100%
”	⅝″	”	40- 60%
”	#4	”	0- 10%
”	#10	”	0- 4%

Wearing Course

Passing	½″	Sieve	100%
”	⅜″	”	95-100%
”	#4	”	35- 60%
”	#10	”	5- 20%
”	#20	”	0- 5%

The use of the above gradation has resulted in the obtaining of surfaces possessing ease of spreading, rolling, and stability. For all plant mixtures of the crushed stone or gravel type, spreading by machine is required. Such spreading has yielded very satisfactory riding surfaces.

Sealing of the crushed stone wearing surfaces is required. The rate of application is specified at .2 to .3 gallons per square yard and is covered with stone chips of ⅜″ maximum size, except where asphalt emulsion has been used, where coarse sand has been specified as the seal coat aggregate.

Bituminous construction practices in Minnesota probably are not materially different from those followed in most other states, except perhaps in our specifications for plant mixes of the dense graded gravel type. We do not provide for the inclusion of any filler material with the result that our mixtures carry approximately 2 to 3 per cent of material finer than 200 mesh after passing through the drying and screening operations. We have found that the use of cut-back asphalts or tar cements with such graded aggregates has yielded us mixtures of high stability, little or no flushing of bituminous material to the surface and greater permissible variation in bitumen content than would be the case where asphaltic oil of the slow-curing type and filler material specified. The mixtures will of course possess lower density which will possibly permit the entrance of moisture but this can be circumvented by the placing of a seal coat.

Developments in Practical Design and Construction of Bituminous Surfaces in Washington

By

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Five principal classes or types of bituminous surfaces, exclusive of asphaltic concrete types used mainly for the resurfacing of old pavements, are being constructed on our highway system. In all cases the operations are a modification of construction methods used the past several years or are complete revisions. We feel much improvement has been made in the wearing surfaces as well as in the construction of the foundation courses.

The types range from low class, light surface treatments to the higher class, thicker mats. Stage construction is employed to a large extent and the lighter surface treatments given newly graded and surfaced highways are utilized as prime coats under heavier mats laid at a later date. The advantage gained by this method of procedure is that practically none of the surfacing material, placed on the roadway by the surfacing contractor, is lost while the roadbed is allowed to settle and assume its permanent position. An opportunity is also afforded to reinforce or repair weak areas before a more permanent type surface is constructed.

Following is a description of each of the five types of bituminous surfaces referred to above with a discussion of each type and the average cost per mile:

(a) Light Bituminous Surface Treatment or Blotter Type: As a perliminary step in the bituminous treatment of any roadway, a prime coat is first given the existing crushed rock or gravel surfacing. Where the surfacing material has been on the roadway for some time and is compacted, the preparation for the prime treatment consists of tight blading of the surface and, if necessary, scarifying lightly in order to remove all irregularities. The roadway is then swept with a revolving power broom to remove all dust and fine particles that will prevent penetration of the bituminous cement.

In the case of uncompacted surfacing, the roadway is brought to a smooth riding surface with blades and rolled, then, as a final operation, a blade equipped with a wire moldboard attachment is driven over the roadway just ahead of the distributor to give the surface a uniform texture and distribute segregated areas of fine aggregates so that streaking will not occur when the asphaltic cement is applied. Sweeping of the new top surfacing material is not attempted.

By applying five-tenths (0.5) to six tenths (0.6) gal. per sq. yd. of MC-2 asphaltic cement in two (2) equal applications and covering with surfacing material, as described below, a three-quarters inch (¾″) mat is formed on the roadway. These in many instances have lasted two years without expensive patching or additional treatment. Where new uncompacted top surfacing is treated, the full five-tenths (0.5) gal. per sq. yd. of MC-2 is applied in one application.

Two methods of covering the spreads of cement are defined in our current specifications. The first method provides for obtaining the cover material from the roadway by blading loose surfacing rock into two equal windrows on each edge of the roadway. One half of each windrow is spread back over the first spread of cement with blades and the remaining material in the windrows is used to cover the second spread of asphalt. Stockpiled top course material (¾″ to Dust) is usually provided to take care of the deficiency of aggregate in the windrow.

An optional method of covering the cement is provided by spreading all new top surfacing rock from trucks backed over the roadway. This method is preferred because of the even spread of aggregate on the surface, but is more expensive and occasionally the additional cost is not justified.

A five day maintenance period is required for this construction, during which time the contractor is required to broom or blade the finished surface, carrying excess material from shoulder to shoulder, covering all areas that are bare and will bleed and removing excess top course material from others. The process is to lightly broom the surface each day, leaving a light covering of fine aggregate evenly distributed over the roadway until the asphalt has cured and all danger of bleeding has passed.

This method of construction is, in our opinion, much superior to our former practice of applying the first application of asphaltic cement and delaying the second application of cement two or three hours and then covering with top surfacing material from the windrows at the sides of the roadway by reason of the fact that traffic is not required to travel over the fresh asphaltic cement and no damage to the surface being constructed, results by having the cement picked up by traffic.

The advantages gained by the use of MC-2 cement as compared with SC-2, formerly used, are believed to greatly outweigh the difference in cost of the two asphaltic cements, and there is a distinct advantage also by the use of the MC-2 material in that:

(1) Once the MC-2 cement has cured and the maintenance period is completed, the roadway does not bleed during hot weather. This is especially true on the west coast where SC-2 treated roads have a tendency to bleed during the summer, destroying the non-skid surface.

(2) A thicker mat is obtained due to the fact that MC-2 holds more surfacing rock in the roadway and in effect acts as a non-skid seal as well as a prime coat.

The density of traffic makes it imperative that some form of bituminous mat be placed on the finished surfacing immediately after the grading and surfacing contractor completes his work. Clay fillers have been eliminated in the construction of the base and surfacing courses and it is therefore difficult to maintain untreated roadway surfaces during dry weather.

COSTS

The average cost per mile of 20 ft. roadway, where 75% of the cover aggregate is bladed from the roadway and 25% is supplied from stockpiles, is approximately $1,000.00 per mile. Where 100% new cover stone is spread on the roadway, the average cost is increased about $200 per mile.

b) Seal Coat Surfaces:

This type of construction is, as the name implies, used for re-sealing older types of bituminous surfaces that have become smooth or slippery for traffic, or porous and abraded. Seal coats are also used as wearing surfaces over the Light Bituminous Surface Treatment prime coat as described under (a) where the foundation is good and it is desired to delay further stage construction of a heavier type of surface. When used for the last purpose, the Seal Coat is placed over the primed roadway either the same year or not later than the following season.

Considerable development has been made the past two years in this light treatment, in that the aggregates are now better graded and suited for the sealing operations and more care is taken to insure against "kick off" by traffic, of the coarse aggregate during the construction and immediately following the construction of the seal coat.

Two types of seal coats are specified for use for the various traffic conditions and are known as the Nonskid Single Seal and Retread Treatment.

The first type, as indicated by its name, consists of one application of from .25 to .30 gallons per square yard of bituminous cement on the prepared bituminous surface, followed by a spread of either three-quarters inch to one-quarter inch or one-half inch to one-quarter inch crushed rock or gravel, at the rate of from 0.011 to 0.012 cubic yard per square yard, which is equivalent to 25 to 35 pounds per square yard. RC-4 cutback asphalt is generally used. The rock is spread by trucks backing over the fresh cement with special spreader boxes bolted or hung from the tail gate to insure an even, uniform spread of rock on the roadway. Next, the distributed rock is lightly broomed, by motor patrol blades equipped with wire broom moldboard attachment, in order to insure an even coverage of the surface with rock and the removal of any excess stone or ridges. The surface is then rolled and additional rock is spread where needed over bare areas. After a final brooming and rolling, the roadway is dusted with a light spread of one-quarter inch to dust material spread at the rate of 0.003 cubic yards per square yard, or approximately eight to ten pounds per square yard. The purpose of the fine screening material is to keep traffic from picking up and throwing the coarse screenings that come in contact with the asphalt and cement and until the cement has cured sufficiently to securely hold the coarse screenings in place. During cool weather or when there is no "pick-up" due to light traffic conditions, the spread of ¼″-0 screenings is often delayed until the following day.

The retread treatment is similer to the above construction, with the exception that only three-quarters inch to one-quarter inch rock is used as coarse aggregate, and after brooming and rolling the coarse aggregate another application of asphaltic cement is made on the coarse aggregate at the rate of .22 to .27 gallon per square yard. Fine screenings are then spread, by backing trucks equipped with spreader boxes over the fresh cement, at the rate of from 0.005 to 0.007 cubic yards per square yard, or approximately 15 to 25 pounds per square yard. The surface is broomed with wire broom moldboard-equipped motor patrols and thoroughly rolled. The contractor is required to maintain the finished surface by brooming excess fine material from shoulder to shoulder of the roadway for a period of ten (10) days.

The Nonskid Single Seal is specified for lighter traffic highways or older type roadways that are not permanently located and at some later date will be reconstructed. An effective thickness of approximately one-half inch (½″) is attained by the construction of the Nonskid Seal Type.

The Retread treatment is specified for heavier traffic highways and roadways that are located favorably and have ideal drainage and foundation conditions and which will carry traffic satisfactorily with a lighter type of bituminous wearing surface. An effective thickness of approximately three-quarters (¾) of an inch is constructed by this type seal and a slightly smoother riding surface is gained.

COSTS

The average cost of the Nonskid Single Seal is $1,000 per mile of 20-foot roadway. The average cost of the Retread treatment is $1,400 per mile of 20-foot roadway. The above costs include the preparation of roadway ahead of the Seal Coat as well as the production of all aggregates and constructing the Seal Coat.

(c) **Road Mix Surface Treatment:** Satisfactory developments have been made within the last two years in the road mix type of construction and considerable mileage is being laid this year on primary as well as secondary highways.

The former inability of obtaining uniformly graded aggregates by scarifying the existing roadway, and the resulting excessively rich or dry sections of mat, has been overcome by producing aggregates for the mat in at least two separate sizes and placing the coarse and fine aggregates on the roadway in correct proportions in order to produce a mixture that has suitable grading for the asphaltic cement to be used.

While the production of 100 per cent new aggregates for the road mix mat has increased the cost of this type, it is felt the added cost is warranted by the results obtained.

In many cases the roadway to be improved has been thoroughly compacted by from one to several years of traffic. To scarify this crushed rock or gravel mat would mean the loss of considerable stability. The addition of new aggregates consequently prevents the disturbing of the foundation and adds strength to the roadway. Over-size rock in the mat is reduced to a minimum and requires less forking during the mixing operations.

MC-2 asphalt cement has been used for the cementing medium in the majority of cases this season. This heavier grade of cement allows the use of coarser aggregate and is more desirable than SC-2 cement formerly used. The MC-2 is less liable to bleed after the mat has been laid and produces a stronger and more durable mat. The use of MC-2 is advocated on all projects where the added cost of the cement warrants its being specified rather than SC-2.

Traveling machines for picking up the aggregates from windrows and mixing the aggregates and asphalt cement on the roadway are allowed under the specifications, but to date none of the contractors operating in this state have elected to construct the mat by this method. Motor patrol blades are used for the mixing and spreading operations.

COSTS

''Road Mix'' costs vary considerably with the location of the project and availability of aggregates. The average cost of one mile of road mix mat two inches (2″) thick and twenty feet (20′) wide, is approximately $4,000 and includes all materials as well as the labor and equipment used in constructing the mat.

(d) **Plant Mix Bituminous Surface**: The success in obtaining uniformly graded mixtures and the successful development of the present road mix construction has made it seem less desirable to specify the more expensive plant mix type surface where cutback or slow-curing asphalts are used as the cement.

Due to this fact, few contracts have been awarded for plant mix and consequently few developments have been made. Self-propelled spreading and finishing machines of the Adnum and Jaeger type are required for spreading all "Plant Mix" mixtures.

Our records of costs of the above type surface do not cover a variety of conditions and, therefore, do not represent average conditions. However, estimates have been made based on present labor and other contributing conditions and one (1) mile of plant mix twenty (20) feet wide, two (2) inches thick is estimated to cost approximately $4,800.00 under our present specifications. This represents the cost of all materials and the production of aggregates besides the actual laying costs.

(e) **Bituminous Penetration Macadam**: Penetration Macadam mats of two (2), two and one-half (2½) and three (3) inch thicknesses are laid in this state. The majority of the contracts call for a two and one-half (2½) inch completed surface.

Two outstanding developments in this type surface are—first, stone is one-half (½) inch less than the total thickness of the pavement, and—second, the base rock is laid by a self-propelled mechanical spreading machine of the Adnum or Jaeger types that spread the rock to desired thickness and contour. A very flat spread of the base rock is obtained by this method and care is taken to prevent the rock from being disturbed before it is thoroughly rolled and penetrated with asphalt cement.

The results of the above developments have been the elimination of the small vibratory roughness characteristic of this type surface from thirty (30) to fifty (50) per cent, as measured by a roughometer, and the ability to lay larger quantities of base rock per day, which in turn makes it possible to increase the contractor's production of finished macadam surface. We feel the present specifications will produce a mat that is of equal quality, smoother riding and easier to construct than was formerly specified.

Aside from the developments outlined above, the usual procedure in laying the penetration macadam mat is followed. Two weeks after the first seal is laid a final single seal of asphaltic cement, covered with one-half (½) to one-quarter (¼) inch screenings, is applied to the surface to thoroughly seal the mat from the infiltration of water and to give the surface a uniform texture and appearance.

Permability Tests are made on all new penetration macadam surfaces laid, and if the mat is porous another seal is placed.

Ninety-five plus asphaltic cement is used for the penetration macadam mat up to the final seal. RC-4 cut back asphalt is used for the final seal. If an additional seal coat is needed a fast breaking emulsified asphalt is used, which is then covered with fine screenings or a coarse sand.

COSTS

The average costs to construct one mile, twenty feet wide of the three depths of mats rated above are as follows: 2″ mat, \$5140; 2½″ mat, \$5830; 3″ mat, \$6690. The above includes all costs to produce and lay the mineral aggregates and bituminous cement in place as well as the cost of average preparation of the base.

RIDING QUALITY TEST

In designing the various types of surfaces and specifying the method by which construction shall be carried on, the riding qualities of each type of surface is considered and provision is made to obtain the smoothest riding surface possible. To accurately measure the riding qualities of bituminous surface, a roughometer was installed during the summer of 1936 on a car owned and operated by the highway department. This instrument is similar to those used by the Bureau of Public Roads, District No. 1 and the California Highway Department and has proved of great value in developing new methods in the construction of the various types of surfaces.

Roughness readings are made on all the higher type surfaces as the work progresses and if the roughness is greater than the standards established for the surface tested, an attempt is made to find the reason or reasons for such roughness and eliminate them if possible. The psychological reactions on the men in charge of the job are favorable in that small details effecting smooth riding qualities are not so apt to be overlooked. A definite measure of smoothness seems to carry more weight in the minds of our field men than an expression of opinion as to the riding qualities of the finished surface.

CONCLUSION

The construction of the several types of bituminous surface treatments and mats as laid today, is, we feel, consistant with the needs and demands of traffic for safer, smooth riding roads with Non-Skid surface texture.

A Hot-Mix, Cold-Lay Asphalt Material and An Improvised Plant for its Manufacture

By

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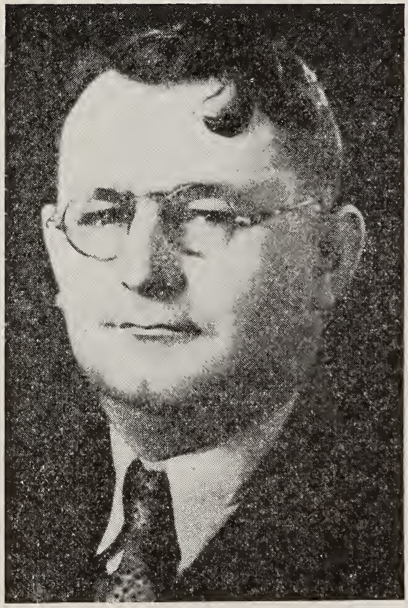

For a number of years the writer has felt the need for a pavement repair material that would utilize local materials where available, and one that could be manufactured at a reasonable cost on the job in small quantities, with a relatively long "workability period," and at the same time, a short "curing period." The advent of high-early-strength cement approached this ideal, but never did completely solve the problem, since it involved relatively high costs with processed materials and a curing period of at least one night, together with the hazards incident to barricades, lights, etc. Bituminous material naturally seemed to automatically come into the picture as the most satisfactory solution, but experience seemed to limit the field to some of the patented types that basically depend on the angular shapes and keying action of the aggregates used for their stability for early use by traffic. Hot mixes, of course, offered the solution for the "early use," but the "workability" period was, heretofore, greatly reduced accordingly, and the long hauls from available plants made the costs rather unfavorable.

After three complete seasons of use and observation, we feel no hesitancy in announcing the apparent solution of the problem, at least with Mississippi climates and materials.

With round, glacial gravel and local, pit-run sand, we can manufacture, on the job, twenty to thirty cubic yards per day of material that can be placed immediately, or within four or five hours, as the occasion may demand, spread, raked and rolled, and then be opened to rubber-tired traffic as soon as the rolling has been completed, and to wagon traffic within two or three hours. The manufacture of this material is simple, and the plant required is also simple and flexible.

Reversing the theory of most of the patented types, the method of attack that we follow is that the grains of sand and the aggregate should have a coating of relatively hard asphalt, for final durability and strength, and that the workability period be secured with a secondary coating of cut-back asphalt. Practice has borne out this theory one hundred per cent, and the workability period can be made as long or as short as may be desired by varying the amount and characteristics of this secondary coating.

To give the filler and fine grains of sand a coating of hard asphalt naturally requires heat, so that for small production we accomplish this by heating the material in a regular, ''non-tilting'' drum concrete mixer with one or more kerosene torch-type burners, to a temperature of 250-300 degrees, Fahrenheit. The torches are then removed from the drum, and the melted hard asphalt is poured in. Any standard heating kettle will serve for melting the Asphalt Cement. For this hard asphalt we generally use a regular 50-60 penetration. After about two minutes of mixing time the cutback is slowly poured into the drum. Since the material in the drum is still hot, a cloud of blue-white vavor rises from the mixer, but no explosion will occur unless a flame is close by. For this reason, the burners and kettle should be kept at least ten feet away, and preferably so placed, that the wind will not blow the fumes from the mixer toward them. For the cutback we generally use an RC-1, made with a viscosity of about 150, penetration of base of about 120, and a naphtha whose end point is about 430. For a workability period of three or four hours we use about equal proportions of the two asphalts. For a longer period, we increase the percentage of cutback, and reduce the Asphalt Cement.

We have found that this combination results in a very satisfactory stability, even though no crushed or angular material is used, and that material from more than one deposit can be readily blended to give a better gradation. Any material that will pulverize in the mixer can be mixed in this manner. A certain per cent of the fines will be blown out of the mix by the draft caused by the burners, and some allowance should be made for this in the initial feed.

It has also been found that more than one blend of asphalt will give good results, except that the period for handling and curing will be changed accordingly.

Care must be used to see that the burners do not discharge any raw kerosene into the drum, and that none is spilled in the truck-bed or on the mix after it is spread.

This mix develops a surprising toughness, yet at the same time does not seem to ever become hard or brittle. After three summers it seems to be immune to any cracks or brittleness, yet does not show any defects from traffic after three or four days.

With a portable dryer (built entirely in our Shop). we have increased the capacity of our two-bag mixer to about forty-five cubic yards per day, yet this plant requires only six men, (exclusive of hauling). The entire plant can be moved with two 1½ ton trucks, and requires no special set up, since we have used it on the shoulder of the road and still carry traffic without serious inconvenience. The dryer was assembled largely from the junk-pile, yet it has been working steadily for nearly one year, and still shows little sign of wear.

This material has been used for thin repairs as well as for bases, in some cases as much as twelve inches thick, and has never shown any signs of corrugation or shoving, and thus far, it seems to be able to ''stand the gaff'' under truck-traffic that has practically destroyed an old concrete road.

Thus we feel safe in stating that thus far, this is the finest cheap repair material that we have seen.

During the winter of 1936-1937 we built a larger dryer along the same general lines as the small one, and rubber-tired, portable, twenty-seven cubic foot mixer. This outfit, hooked up to natural-gas lines, has been turning out about ten cubic yards of hot-mix per hour, regularly, handling a blended-mix as described above, as well as quite a lot of straight 85-100 penetration asphaltic-concrete mix with fines, etc. The quality of the mix seems just as good as any pug-mill mix could be.

We will be glad to furnish details of this plant or material to any one who may be interested.

Developments in Practical Design and Construction of Bituminous Surfaces in Montana

By
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Montana has a highway system of approximately 5,500 miles. This mileage in a state with only a half a million population has made it necessary for the Highway Commissioners and Engineers in charge of the work, to do considerable planning to spread the money as far as possible and still construct serviceable roads.

In the early stages of Montana's Progressive Road Program the chief aim was to "get out of the mud," but after the construction of gravel roads the public was not long in demanding dustless highways.

Montana started its major oiling program in 1929 when some road mix surfaces were built and also some surface treatments were completed by Special Maintenance crews.

Following the program of 1929, every year a substantial mileage of Road and Plant mix as well as Surface Treatments have been added using various grades of Road Oil and Cutbacks.

ROAD MIX

In the road mix contracts in Montana's early program Road Oil similar to the present SC-2 was used and these mats were three inches in thickness and traffic compacted. No seal coat was applied.

The crushed material used in the above mixes were required to meet the following specifications:

Gradation Table

Size	**Per Cent**
Passing a ¾ inch screen (circular)	100
Retained on a ¼ inch screen (circular)	50-75

The fine aggregate (that passing a ¼ inch screen) may contain such a quantity of clay that the percentage of clay in the entire mass of surface material shall not exceed fifteen (15) per cent.

In July of 1932, a contract was awarded with the use of 72+ Road Oil. This grade of oil proved to be very satisfactory, the cost of applying the oil and processing amounting to $825.00 per mile. The mat was three inches thick, 20 feet wide and traffic compacted. About 20,000 gallons of oil were used per mile and no seal coat was applied. The grading of the crushed material was similar to the specifications mentioned previously under the early road mix types with SC-2 Road Oil.

SC-3 Road Oil was used in all the road mix contracts awarded in 1933 and 1934.

The crushed gravel used in the above road mixes met the following grading requirements:

Gradation Table

Size	**Per Cent**
Passing a ¾ inch screen (circular)	100
Passing a ¼ inch screen (circular)	40-65
Passing a 10 mesh sieve	30-55
Passing a 40 mesh sieve	15-35
Passing a 200 mesh sieve	5-15

Some of these surfaces were sealed with RC-1, while others were sealed with SC-3 and covered with stone screenings. The stone screenings consisted of broken stone, pea gravel, or course sand and were of such size that all would pass a screen having ½ inch circular or square openings and not less than 85% retained on a screen having ⅛ inch square openings.

Montana in 1934 and 1935 completed one of its largest oiling operations. 704 miles were contracted under a P.W.A. allotment. SC-3 oil was used and the typical section on this work called for a 22 foot mat, with a compacted thickness of 1½ inches. Rolling was included in the bid price per mile of processing and all these jobs were sealed with approximately one-tenth of a gallon per square yard of RC-1. The cost per mile for this work was approximately $2,700.00.

In 1936 and 1937 the tendency on all road mix work has been to use MC-2 or MC-3 cutback in the mix, however, it has been found that MC-3 is difficult to process if cool or rainy weather is encountered. In a few instances where there is danger of sub-grade trouble and the mix will probably be torn up by traffic, SC-3 oil has been used.

All the work let to contract in the last two years has specified a 2½ inch compacted mat. They have all been rolled and sealed with RC-1, without cover material.

PLANT MIXES

In 1931 the first plant Mix contract was awarded South of Dillon in Beaverhead County. No. 2 Road Oil was used in the mix and also used in tacking the compacted base. The mat was not rolled or sealed.

The crushed materials were graded to meet the following requirements:

Gradation Table

Size	Per Cent
Passing a screen having 1¼-inch circular openings or 1-inch square mesh openings	100
Passing a screen having ¼-inch circular openings not more than	65
Passing a 10-mesh sieve	30-55
Passing a 200-mesh sieve	5-15

In 1931 and 1932 two Plant mix projects were completed using native decomposed granite sand.

The granite sand meets the following specifications:

Gradation Table

Size	Per Cent
Passing ¾ inch screen (square or circular)	100
Passing ¼ inch screen (square or circular)	80-100
Passing a 10-mesh sieve	40-80
Passing a 200-mesh sieve	2-10

Approximately 4.25% by weight of 72+ Road Oil was used. The mat was 3 inches thick and roller compacted. These two projects are between Butte and Helena and the sub-grade was built of similar material which was swept and tacked with No. 1 Road Oil.

These projects were sealed with 72+ Road Oil and a sand cover course. This cover course was so graded that all of it passed a screen having a ¾ inch circular or square openings and at least 40% was retained on a 10 mesh sieve.

In 1933 a section of highway near Deer Lodge was let for contract using 95+ Road Oil. This mix set up too rapidly to get a good riding surface, however, with the new types of spreaders, improved riding conditions would result and the use of this type of Road Oil should make a very satisfactory mat, as to date this section has had little surface maintenance.

The crushed material used with the 95+ Road Oil met the following requirements:

Gradation Table

Size	**Per Cent**
Passing a screen having 1¼-inch circular openings or 1-inch mesh openings	100
Passing a screen having ¼-inch circular openings not more than	65
Passing a 10-mesh sieve	30-55
Passing a 200-mesh sieve	5-15

This mat was three inches in thickness and was Roller compacted. It was sealed with 95+ Road Oil and stone screenings of such size that all would pass a screen having ½-inch circular or square openings and not less than 85% would be retained on a screen having ⅛ inch square openings.

On this work a thickened edge was constructed where the mat was approximately 5 inches thick.

This did not prove satisfactory as some over-size rocks were torn up by the blade when making the small trench for the reinforced edge.

In 1934 several plant mix contracts were awarded using SC-4 Road Oil. This mix was windrowed in the center of the roadway and spread to the proper width and depth with motor patrols.

This was usually done during the hottest part of the day as this mix was difficult to handle when chilled to any extent. These mixes were rolled and sealed with RC-1, without cover material.

In 1935 a contract was awarded for a RC-3 cutback plant mix between Helena and Great Falls. Several experimental sections were constructed using different proportions of material passing the No. 10 sieve. These proportions were from 5 to 20% and all proved satisfactory. The material was deposited through an improved type of spreader box and immediately rolled. This mix was 2½ inches thick and was sealed with RC-3 cutback and rock chips. This makes a very hard surface and any settlement in the sub-grade since the completion of the contract has caused the mat to crack rather than break up.

In 1936 several contracts were awarded using MC-4 and MC-5 cutback. These were near Helena and have proved satisfactory but the tendency on some of these mixes has been to get the oil content a little low causing the mix to ravel with the changes in climate encountered in this region. The material was windrowed in the center of the roadway and then spread to the required width and depth with motor patrols. The mat is 2½ inches in thickness, roller compacted and sealed with RC-1.

The grading of the crushed material used in the above mentioned mix is as follows:

Gradation Table

Size	Per Cent
Passing a ¾-inch screen (circular)	100
Passing a ¼-inch screen (circular)	40-65
Passing a 10-mesh sieve	30-55
Passing a 40-mesh sieve	15-35
Passing a 200-mesh sieve	5-15

The cost of this type of mat 24 feet in width is approximately $9,000 per mile which includes the cost of compacting the cushion course of gravel and tack coating with MC-1.

SURFACE TREATMENTS

Montana has many miles of the so-called "surface" or "Blotter'' treatments. Practically all this work has been done by Special Maintenance oil crews. The early surface treatments consisted of the application of 0.3 to 0.4 of a gallon of SC-2 and SC-4 oil, each application covered with crushed material, minus one inch.

Lately MC-1 has been substituted for the SC-2 in the first application.

This type of treatment answered the public's demand for a dustless road in addition to conserving the gravel. Many miles of this type of oiled surface has been constructed at the approximate cost of $800.00 per mile, over half of which was for Road Oil or Cutback.

In conclusion many questions enter our minds with reference to the Developments in Design and Construction, which I will not attempt to answer, but will list for your consideration.

1. Which will give the better riding surface, an improved type of spreader or motor patrols with a long wheel base?

2. Is the saving incurred by using a RC-1 paint seal worth the elimination of the non-skid effect of a seal with a heavier oil or cutback covered with sand and chips?

3. If the sub-grade is constructed correctly, would it not be more economical to use a heavy grade of SC oil rather than a heavy grade of MC or RC cutback?

4. Does the thickness of the mat make a great deal of difference if the sub-grade is compacted correctly or if so where is the dividing line with reference to the amount of traffic?

Developments in Practical Design and Construction of Bituminous Surfaces

By
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The type of bituminous surface is closely correlated to the method of maintenance, and bituminous construction to be successful must have its design based upon the type of maintenance to be employed. In Oregon the maintenance of bituminous surfaces is based upon the use of Extra Gang Hot Plant patching of such character and refinement that the condition of the roadbed is maintained in a state equivalent to its original construction. Every bituminous surface is designed adequate for its traffic, or as a step in stage construction as traffic increases, and no design contemplates reworking or remixing at any future time. This idea, therefore, presupposes that the roadbed and surfacing will be of a stable nature, and every attempt is made to construct the surfacing with adequate thickness and strength. The ultra-flexible type of surfacing was soon found unequal to the climatic conditions and was discarded in favor of heavy bases and adequate surface thickness. All penetration work is based upon hot asphalt as neither cutbacks nor emulsions have shown comparable ability to hold aggregate and have been discarded except for prime or seal coats in special instances or patching during the winter season.

Asphaltic concrete has been in increasing use since 1914, oiled macadam since 1924 and bituminous macadam since 1927; and therefore, our experience is the net result gained from the construction of the following mileages of State Highways:

Type	Am't. Miles	Av. Cost per Sq. Yd. Pavement Only
5″ Asphaltic Concrete	718	\$1.30-\$1.60
1½″-2¾″ Bituminous Macadam	604	0.40- 0.55
2½″ Road Mix	100	0.40
¾″-1¼″ Oiled Surfacing	2070	0.20- 0.30

Asphalt from California petroleums is used exclusively and is of 50-60 penetration in asphaltic concrete and 120-150 penetration in macadam. In the lighter surface treatments No. 3 road oil (95+) is generally used. These grades have been found satisfactory throughout all sections of the state even though temperature ranges from an occasional winter temperature of –50° Fahrenheit in the mountain passes or high tablelands to 110° Fahrenheit during the summers. The precipitation varies from 5 inches in the arid sections of Eastern Oregon to 80 inches along the Pacific Coast.

The various types of bituminous surfacing customarily used by the Oregon Highway Department are:

A. Asphaltic Concrete Pavement.
B. Asphaltic Concrete Resurfacing for Either Asphaltic or Cement Concrete Pavement.
C. Pavement Non-Skids.
D. Bituminous Macadam.
E. Oil Surface Treatments.
F. Road Mix.
G. Dust Palliatives.

SOIL STABILIZATION

Oregon has found it necessary to increase the stability of soils even under the heavier pavements and has found the most economical manner is by the use of a ballast of quarry stone, talus or gravel. The state is abundantly supplied with both excellent basaltic rock (abrasion 2 to 6%) and hard gravels in nearly every section, and it is more economical and certainly more permanent to effect stabilization with these natural materials than to attempt it by artificial admixtures, of either the bituminous or chemical type. We have experimented with bituminous stabilization by the use of emulsified asphalt and have found the cost to be about $0.30 per square yard for a 4-inch depth. This sum would provide for a gravel stabilization 6 to 10 inches deep which cannot fail to be more lasting. Sound rock or gravel is a permanent addition to the roadbed; whereas, any chemical stabilization must be of more or less temporary nature due to leaching, and asphaltic stabilization may result in subsequent movement unless the amount of asphalt is carefully controlled.

Under pavements of adequate slab strength the preferred base is of the gravel ballast type, composed of 4″ minimum thickness of pit-run gravel covered with a sand cushion of such thickness, between ¼″ and ¾″, as is necessary to smooth up the gravel base, fill all the voids and provide a non-clinging surface upon which to found the pavement. Containing no 200-mesh material, it affords drainage similar to railroad ballast. The thickness of ballast is increased to as much as 12″ when bad soils are encountered.

Under bituminous macadam and oiled surfaces of low slab strength a base of more dense type is used in order to prevent its displacement into traffic grooves under heavy truck traffic. Sledged quarry run stone, talus rock or angular gravels are desired. Most bank gravels contain sufficient angular particles to afford a stable foundation, but gravels excavated from the bed of large rivers cannot be consolidated even with artificial filler, and are, therefore, avoided.

Bases bound with clay are extremely treacherous and many now preaching the indiscriminate use of clay and roadside fillers in bases can well profit from Oregon's experience. Prior to the re-introduction of bituminous surface treatments, Oregon constructed a large mileage of clay or roadside filler bound macadam similar in construction to the so-called stabilized bases so fashioned at present. These were very successful under blade maintenance, and it so happened that the first successful light oil mat surface treatments were laid upon these bound bases. The practice of filling loose gravel roads prior to surface treatment was generally adopted. but it soon became evident that failures were occurring in the oil mat wherever capillary water was present, and very extensive studies attributed these failures to unsound clay filler. There have since been many formulae written for testing clay filler, none of which are so positive that they can be used without great care and judgment. Our experience with delinquescent alkalies occurring naturally in arid soils leads us to the firm conviction that bases to be oiled should not be stabilized by use of calcium cloride, as oiled roads have been unstable over bases containing any such alkaline filler. The most satisfactory gravel bases are traffic and blade compacted over a period of at least one year. Any filler should be added slowly in minute quantities throughout the period, and if not of an inert mineral nature, should be laboratory tested to guard against unsoundness and high shrinkage.

ASPHALTIC CONCRETE PAVEMENT

Asphaltic concrete as now laid in Oregon is a very popular and serviceable type of pavement. When the center is striped with a yellow line, it gives a very adequate surface for night driving free from glare from the on-coming lights, and the yellow line stands out readily in fogs. Asphaltic or cement concrete pavements at present are used in Oregon only on the Class A highways where the traffic is more than 1500 cars per day with a considerable volume of freight traffic.

Construction practice has been simplified by the elimination of the lean Class ''D'' and ''E'' foundation mixes as insufficient saving was made to compensate for the trouble caused by raveling in cold weather. The three classes of asphaltic concrete now in use are shown in the table below. The classes differ from one another in the size of aggregate and in proportions of aggregate and asphalt. Class ''C'' is used for base courses of more than 2″ depth, Class ''B'' for thin smoothing courses and Class ''A'' for thin base courses or for wearing surfaces with a coated screening surface finish.

	Class "A" Asphaltic Concrete	Class "B" Asphaltic Concrete	Class "C" Asphaltic Concrete
Size of screen which all aggregates must pass	1¼-in.	¾-in.	2¼-in.
Percentage of aggregate, 2¼-in. to 1¼-in.	....	....	16 to 26
Percentage of aggregate, 1¼-in. to ¾-in.	16 to 24	....	12 to 20
Percentage of aggregate, ¾-in. to ¼-in.	24 to 36	26 to 28	18 to 28
Percentage of aggregate, ¼-in. to 10-mesh	12 to 20	22 to 30	10 to 16
Percentage of aggregate, 10-mesh to 200-mesh	20 to 28	25 to 35	16 to 24
Percentage of aggregate, passing 200-mesh	3 to 6	4 to 7	2 to 4
Percentage of asphalt	4.5 to 6.5	5 to 8	3 to 5

WEARING SURFACE—COATED SCREENINGS

Wearing surfaces are of two types. The standard Class A asphaltic concrete mix is covered with a surface finish coat consisting of heated ¾″-¼″ coarse aggregate coated with 2% asphalt. About six pounds per square yard is spread uniformly over the pavement. This affords a non-skid texture which has been quite successful on those jobs where the weather was uniform during the progress of the work, but during seasons of very changeable weather considerable difficulty has been experienced in incorporating the coated aggregate uniformly into the pavement. Where the coated screenings show a tendency to loosen or the pavement shows a too open texture, a coating of emulsified asphalt applied at the rate of .18 gal. per square yard is a very practical cure and will not lessen the non-skid qualities.

WEARING SURFACE CUTBACK

In order to avoid the difficulties inherent in coated screening wearing surfaces, we have developed a cutback asphalt wearing surface which has been very successful in presenting a uniform appearance and retaining its non-skid characteristics. It is very easily spread by a simple strike off template, and therefore, adapted to street sections wider than the ordinary finishing machine. The specifications for cutback wearing surface are:

The bituminous cement shall be heavy grade cutback asphalt (RC-4) conforming with the requirements stated in Section 46 of the standard specification form.

The materials of which the wearing surface mixture is composed shall be of such sizes and gradings that, when proportioned and mixed together, they will produce a uniform mixture, which when tested by means of laboratory screen, will conform to the following requirements:

	Percentages
Passing ¾-inch screen and retained on ¼-inch screen	45 to 55
Passing ¼-inch screen and retained on 10-mesh sieve	30 to 36
Passing 10-mesh sieve and retained on 200-mesh sieve	8 to 14
Passing 200-mesh sieve	0 to 2
Cutback Asphalt (RC-4)	4 to 6

The exact proportions of the several constituents to be used in the production of the bituminous mixture shall, within the limits above specified, be fixed by the Engineer, and the proportions so established shall be changed only upon his order.

All percentages stated in this specification are percentages (by weight) of the complete asphaltic concrete mixture including the weight of the cutback asphalt. Screens for determining the percentages of different sizes of aggregate shall in all cases have square openings.

The aggregate passing the 10-mesh sieve shall meet the following requirements:

	Percentages
Passing 10-mesh sieve and retained on 40-mesh sieve	42 to 62
Passing 40-mesh sieve and retained on 80-mesh sieve	10 to 22
Passing 80-mesh sieve and retained on 200-mesh sieve	10 to 22
Passing 200-mesh sieve	10 to 22

Preparatory to the proportioning of the materials, the aggregates shall be heated to a temperature between 150 and 200 degrees, Fahrenheit.

Preparatory to mixing, the cutback asphalt shall be heated to a temperature between 125 and 175 degrees, Fahrenheit.

The asphaltic concrete mixture shall leave the mixing plant at a temperature between 135 and 175 degrees, Fahrenheit, and when deposited on the road it shall have a temperature not less than 125 degrees, Fahrenheit.

The rolling of the cutback asphalt wearing surface will not be considered completed until the specific gravity of the compacted material is not less than eigthy (80) percent of the specific gravity of the combined aggregate.

METHOD OF CONSTRUCTION

Great care has been taken to secure a bond between the older and new pavement in resurfacing work, and we have had no trouble whatsoever from any separation of the two courses. The surface of the old pavement is thoroughly cleaned and heated immediately before covering by spraying gasoline or distillate upon it and igniting the same. Following the heating of the surface of the old pavement, it is spread lightly with heated or emulsified asphalt.

FORMS

On account of the limited amount of pavement work and the cheapness of lumber, wood forms are universally used. In order to secure lateral stiffness we require a horizontal thickness of not less than 4 inches. The top of the wood forms are temporarily faced with steel strips during the passing of the paving machine.

SPREADING AND FINISHING

Mechanical spreading and finishing machines are required on all jobs, and the smoothness of 1/10″ in 10 feet is required.

AGGREGATE

The coarse aggregate shall be either crushed rock, or if crushed gravel must be crushed from gravel in which all material passing the 2″ screens has been eliminated.

ASPHALT

California asphalt to penetrate 50-60 is used in all asphaltic concrete.

ASPHALTIC CONCRETE RESURFACING

Asphaltic concrete is commonly used as a resurface for the older and narrower pavements, of which there was a large mileage constructed in Oregon at the beginning of the Highway regime. The widening of bituminous pavement is usually accomplished by excavating a trench alongside the old pavement of sufficient depth for an 8-inch foundation of well compacted crushed rock. The resurfacing and widening is then accomplished by either Class A, B or C standard mix, depending upon the thickness available to the new crown. Since the older pavements were built with a much greater crown than the newer ones, there is usually a two or three inch covering over the joint between the old pavement and the widening which is ample to prevent cracking. The resurface is finished by a coated screening or cutback wearing surface. We formerly thought it advisable to require 1½″ minimum thickness of resurfacing exclusive of wearing surface, but experience has enabled us to reduce this to ¾″ without unfavorable results.

Asphaltic concrete resurfacing and widening of cement concrete is successfully done in a manner similar to the resurface described for asphaltic concrete. As a factor of safety, the minimum thickness used is 2 inches composed of ¾″ leveling course and 1½″ wearing course, as it is more difficult to make a perfect bond between asphaltic and cement concrete. A course of this thickness will retain its shape and position even though not perfectly bonded. However. many thin mats of oil resurfacing on concrete have been used so that there is little reason or doubt but that an asphaltic concrete resurface of ¾″ minimum thickness would be practical. The original pavement in certain instances was badly cracked so that no blocks were larger than 4 feet square, which probably is the reason that no contraction cracks have transferred through the black pavement since expansion and contraction of the base was minimized. A resurface over full slabs would probably crack at the expansion joints.

PAVEMENT NON-SKID

Due to the fact that many miles of asphaltic concrete pavement with high asphaltic content were constructed in Oregon during early days, we have found it necessary to non-skid them with a 3-course treatment based upon our 1¼″ surface treatment, except that the asphalt content is cut down to approximately 3½%. The cost of the 3-course treatment including stone is approximately 25 cents per square yard. This surface treatment is frequently combined with the bituminous macadam widening for narrow pavements. Prior to the non-skidding, it is preferable that the pavement be planned in order to remove the excess asphalt and smooth out the irregularities. The following is the table of details for Non-Skid:

1. **General Details:**	
Thickness of non-skid surface	1⅛ inches
Number of courses	Three
Kind of bituminous cement	Asphalt
2. **Order and Rates of Spreading:**	
a. First Application:	
Spread bituminous cement	0.15 gal. per sq. yd.
Spread 1½″-¾″ aggregate	0.022 cu. yd. per sq. yd.
b. Second Application:	
Spread bituminous cement	0.20 gal per sq. yd.
Spread ¾″-½″ aggregate	0.010 cu. yd. per sq. yd.
c. Seal Coat:	
Spread bituminous cement	0.30 gal. per sq. yd.
Spread ½″-¼″ aggregate	0.008 cu. yd. per sq. yd.
Spread ¼″-0″ aggregate	0.003 cu. yd. per sq. yd.
3. **Total Quantities:**	
Bituminous Cement	0.65 gal. per sq. yd.
Aggregates	0.043 cu. yd. per sq. yd.

BITUMINOUS MACADAM

For surfacing where the volume in weight of traffic and climatic conditions do not justify pavement, Oregon uses bituminous macadam. Many hundreds of miles of that type of construction are in use. The adoption of this surface was made advisable by the abundance of excellent basaltic rock available in nearly every section of the state. This type has been standard for many years throughout New England and the European countries and presents no uncertain problems as to permanence and strength. The strength is furnished by the interlocking of the coarse aggregate, and the bituminous cement merely furnishes the binder and water-proofing. The voids in the base offer an opportunity for contraction and expansion, and no contraction cracks are ever present even in the most severe climates where wide and frequent cracks are found even in asphaltic concrete. It offers a stable permanent type of surface which cannot be displaced by the traffic; nor does it corrugate when capillary moisture is present underneath the surface. If lack of seal or failure of the subgrade causes the surface to craze, or form so-called "alligator cracks," a reseal or hot patch will stabilize the cracked portion without tearing up the road or interfering with traffic.

SEAL COAT

For success in cold climates it is essential that bituminous construction be well sealed and in an endeavor to accomplish this Oregon for several years used a double seal in which the second seal was cutback asphalt, RC-3, or emulsion, the second seal being laid at least 10 days after traffic had used the first seal. The specification for this seal was as follows:

First Application:	
Spread bituminous cement	0.28 gal. per sq. yd.
Spread ½"-¼" aggregate	0.006 cu. yd. per sq. yd.
Spread ¼"-0" aggregate	0.003 cu. yd. per sq. yd.
Second Application:	
RC-3	0.25 gal. per sq. yd.
Spread ½"-¼" aggregate	0.006 cu. yd. per sq. yd.
Spread ¼"-0" aggregate	0.004 cu. yd. per sq. yd.

During 1936, however, a single seal of heavier amounts was used, the bitumen being of the same grade asphalt as in the remainder of the job. This seal was proportioned as follows:

Bituminous cement	0.45 gal. per sq. yd.
½"-¼" screenings	0.008 cu. yd. per sq. yd.
¼"- 0" screenings	0.004 cu. yd. per sq. yd.

The latter seal is much less expensive to lay, as contractors find the interval between the two seals very inconvenient. The single seal is satisfactory if laid to cure during warm summer weather, but the double seal is recommended if laid during the fall months.

BASES

Bases for bituminous macadam are usually built from run-of-bank gravel or talus. These bases are covered with a layer of broken stone to give smoothness, or on important roads with one course of keyed macadam construction. Where gravel or talus is not readily available, keyed macadam construction using stone of 4½" maximum size is preferred.

The B-11 type of bituminous macadam wearing surface is as follows:

1. **General Details:**

Thickness of wearing surface	2¾ inches
Number of courses, exclusive of seal coat	Three
Kind of bituminous cement	Asphalt

2. **Rates of Applying Materials:**

a. First Course:	
Spread 2¼"-1¼" aggregate	0.060 cu. yd. per sq. yd.
b. Second Course:	
Spread bituminous cement	1.05 gal. per sq. yd.
Spread 1¼"-¾" aggregate	0.020 cu. yd. per sq. yd.
c. Third Course:	
Spread bituminous cement	0.40 gal. per sq. yd.
Spread ¾"-½" aggregate	0.008 cu. yd. per sq. yd.
Spread ½"-¼" aggregate	0.004 cu. yd. per sq. yd.
d. Seal Coat:	
Spread bituminous cement	0.45 gal. per sq. yd.
Spread ½"-¼" aggregate	0.008 cu. yd. per sq. yd.
Spread ¼"-0" aggregate	0.004 cu. yd. per sq. yd.

3. **Total Quantities:**

Bituminous cement	1.90 gals. per sq. yd.
Aggregates	0.104 cu. yd. per sq. yd.

The B-12 type calls for the following:

1. **General Details:**

Thickness of wearing surface	2¾ inches
Number of Courses, exclusive of seal	One
Kind of Bituminous Cement	Asphalt

2. **Rates of Applying Materials:**

a. Main Course:	
2½"-1¼" Rock	0.07 cu. yd. per sq. yd.
Bituminous Cement	1.45 gal. per sq. yd.
¾"-½" Rock	0.018 cu. yd. per sq. yd.
½"-¼" Screenings	0.004 cu. yd. per sq. yd.
b. Seal Coat:	
Bituminous Cement	0.45 gal. per sq. yd.
½"-¼" screenings	0.008 cu. yd. per sq. yd.
¼"-0" Screenings	0.004 cu. yd. per sq. yd.

3 **Total Quantities:**

Bituminous Cement	1.90 gal. per sq. yd.
Aggregates	0.104 cu. yd. per sq. yd.

OIL MAT SURFACE TREATMENTS

On roads carrying less than 1000 car per day or roads carrying a moderate amount of truck traffic an oil mat surface treatment is used, either of the 0-11 or the 0-9 type, specificaitons of which follow. The 0-11 is used on State Highways and the 0-9 on secondary or minor roads. The cost of the 0-11 type is approximately 30 cents per square yard including rock, and the 0-9 type about 20 cents per square yard. The specifications for oil mat surface treatment are as follows:

0-11 Type Specifications:

1. **General Details:**

Thickness of oil mat	1¼ inches
Number of courses exclusive of seal	Two
Kind of bituminous cement	No. 3 Road Oil

2. **Order and Rates of Spreading:**

a. First Course:	
Spread bituminous cement	0.25 gal. per sq. yd.
Spread 1¼"-¾" aggregate	0.022 cu. yd. per sq. yd.
b. Second Course:	
Spread bituminous cement	0.40 gal. per sq. yd.
Spread ¾"-½" aggregate	0.008 cu. yd. per sq. yd.
Spread ½"-¼" aggregate	0.004 cu. yd. per sq. yd.

c. Seal Coat:

Spread bituminous cement	0.40 gal. per sq. yd.
Spread ½″-¼″ aggregate	0.008 cu. yd. per sq. yd.
Spread ¼″-0″ aggregate	0.004 cu. yd. per sq. yd.

3 **Total Quantities:**

Bituminous Cement	1.05 gal. per sq. yd.
Aggregates	0.046 cu. yd. per sq. yd.

0-9 Type Specifications:

1. **General Details:**

Thickness of oil mat	⅝ inch
Number of courses exclusive of seal	One
Kind of bituminous cement	No. 3 Road Oil or Tar

2. **Order and Rates of Spreading:**

a. Main course:

Spread bituminous cement	0.20	gal per sq. yd.
Spread ¾″-½″ aggregate	0.13	cu. yd. per sq. yd.

b. Seal Coat:

Spread bituminous cement	0.375-0.50	gal per sq. yd.
Spread ½″-¼″ aggregate	0.008-0.12	cu. yd. per sq. yd.
Spread ¼″-0″ aggregate	0.005	cu. yd. per sq. yd.

3. **Total Quantities (Exclusive of Binder Course):**

Bituminous Cement	0.575-0.70	gal. per sq. yd.
Aggregates	.026- .032	cu. yd. per sq. yd.

ROAD MIX SURFACES

Road mix surface treatments are confined to the arid sections of the state where there is available gravel more adapted by reason of size and abrasion to mixing than to surface treatment, and where there is lack of moisture to consolidate the base sufficiently for an oil mat surface treatment. A limited amount of such construction has been used and has been confined strictly to the locality where this material is available. When the road mix surface treatments were first developed with the use of SC oils, their design was predicated upon the fact that they would remain in more or less a soft state with a hard glazed topping and could, therefore, be easily scarified and reworked from time to time as they became roughened or distorted. This is contrary to Oregon's theory of construction which strives to produce a surfacing sufficiently rigid as to remain suitable for such patching as it is necessary to give from time to time to remove the slight inequalities developed. It was felt that nothing short of an asphaltic concrete could have materials of such exact gradation as to prevent displacement into traffic grooves or corrugations. Even the first asphaltic concrete pavements were very prone to groove under heavy truck traffic, and it was only by the careful gradation of the crushed aggregate and the reduction of the asphalt content that stability was obtained.

For this reason, therefore, Oregon had adopted the penetration type of construction which depends for stability upon the interlocking of crushed aggregates and has reserved road mix treatments to those sections where no such aggregates are available. However, even in these latter locations, we feel that the lack of gradation must be compensated by as heavy an asphalt as possible and have therefore, used RC-3 exclusively in our mixing operations. We cannot believe that MC-2 has any place in road construction as our laboratory tests clearly indicate that it is not possible for kerosene cutback to be absorbed in the aggregate or to evaporate entirely from the mixture, and we are convinced that it affords a dangerous lubricating agent to eventually cause corrugations and traffic grooves. We have experienced no brittleness with RC-3 during the winter and are quite convinced that asphalts of such ductility as result from MC products are unstable for permanent road surfacing and will eventually cause inherent defects in the road which will necessitate scarifying.

We have found little difficulty in using RC-3 in a road mix during ordinary summer weather, particularly if the 200-mesh material is below 3%. It is probably easier to mix RC-3 with those percentages than to mix MC-2 with 8 to 14% of 200-mesh. Road mixes are sealed with RC-3 covered with ½″-¼″ screenings. Our specifications for road mix surface treatments provide that the original surfacing of the road shall be augmented by sufficiently new material to give the requisite stability for the traffic expected and then shall be covered with a prime coat of RC-3 at the rate of three to five-tenths gallon per square yard over a width 2 feet wider than the finished road mix, after which the road mix aggregate is deposited on the roadbed, and special care is used that none of the prime coat is torn up during the mixing. A great deal of the uncertain results in road mix are due to the ununiform amount of material obtained by tearing into the mixing floor. It is also perfectly obvious that a road mix should consist of entirely new material and be not constructed by scarifying the existing roadbed, as there is insufficient slab strength in the mixture itself to support the load without the help of a well consolidated base. The cost of such road mix with a 2½″ thickness has averaged about 40 cents per square yard.

DUST PALLIATIVES

Oregon started the road program in 1924 with a type of construction similar to the so-called ‘‘dust palliatives’’ and speedily found that the cost of maintenance of such type of construction was so excessive that it could not be continued. However, it is occasionally used on roads where the dust problem has become unusually bothersome, and where funds cannot be spared for a more permanent type of construction. We feel that gravel or crushed rock will give more adequate service throughout the 12 months than were the road covered with dust palliative. In other words, the gravel road will be much superior during 9 months of the year and thus more than offset any temporary advantage which the dust palliative would give during the summer.

Developments in Practical Design and Construction of Bituminous Surfaces in Iowa

By

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INTRODUCTION

The early period of bituminous construction in the State of Iowa was without premeditation or logical planning.

A demand to get something started was thrust upon the Highway Department with little warning and in the fall of the year when normally bituminous construction should be nearing completion.

Personnel experienced in this type of work, either as to bitumens or aggregate, was not available and through necessity the department hurriedly made an attempt to meet this demand.

With the demand "get something started," a hasty search was made for some means of "getting wise" quickly. It was found that one of the neighboring states was even then constructing bituminous surfaces, and the inference was erroneously made that a short visit to "the field of action" would reveal all that was necessary for proceeding with the work in this state.

In accordance with this theory, a representative of the highway department made a brief visit to a neighboring state where considerable work was still in progress and upon their return, the contemplated work in this state was begun.

ORIGINAL CONSTRUCTION

Construction and design during the years 1930 to 1933, inclusive, was largely based on "rough and ready" methods rather than on intelligent design.

Some experimental work was carried on during this period, but since little experimental data from other agencies was available, such work was necessarily confined to the ground work of fundamentals of aggregate and grading of mixtures.

During this period the type of surfacing was confined to light mats and other than the experimental projects, construction was generally according to the following method:

A. Loose material from the road bed was bladed to one road shoulder.

B. Primer bitumen of the R.O. type was applied at the rate of four-tenths gallon per square yard from shoulder to shoulder.

C. Immediately behind the distributor, the loose material from the shoulders was bladed over the prime to blot up the excess primer bitumen and protect traffic, partially at least, from the fresh bitumen.

D. After the road was fully primed and blotted, the blotter material was removed by blades and placed in a windrow. Binder bitumen of the R.O. type was applied in increments according to the total quantity as determined by the Wyoming formula in use at that time.

E. The bitumen and aggregates were mixed by the use of blades or other suitable equipment.

F. The mixed material was spread over the full width of road bed and compacted by traffic or any type of roller which might be available.

G. As traffic caused rutting or other distortion of the mat, the surface was bladed lightly to remove surface irregularities.

It is interesting to note that surface failures during the early life of these projects was largely the result of unstable subgrades or high moisture content in the finished mix.

However, after some three or four years, excessive raveling and pot holing occurred quite generally where highly "cracked" bitumens were used.

Probably the most important development during this period was an attempt at least, to draw conclusions regarding the causes of failure and to adopt tentative methods to overcome known deficiencies in current practice.

1934 CONSTRUCTION AND DEVELOPMENT

In formulating the 1934 bituminous program two changes in design were introduced.

A. A method of base strengthening was devised and

B. An attempt was made to improve the surface treatment by
  1. Improving the gradation for light mats, and
  2. By introducing the "blotter type" surface as an alternate method.

Base strengthening was incorporated for about one-half of the mileage for the year's program, of two general types:

A. Stabilized gravel using pit run or crushed gravel with a soil binder.

B. Reconstructed base using crushed rock bound with rock chips, dust, and water.

Although, in general the bituminous surface for the year's program consisted of the "blotter type," yet "mats" were used on a few projects.

Further than this a wide variety of bitumens were used, both as primers and binders, in order to determine if possible, the types and grades best suited to our needs.

The general method of construction of the "blotter type" surface during the year was as follows:

A. Loose material from the road bed was bladed to the shoulders to be used as cover aggregate. Additional aggregate was added to that removed from the road bed to give a uniform quantity of 250 cu. yds. per mile.

B. The road bed was primed with light viscosity bitumens at the rate of approximately five-tenths gallon per square yard applied to the center twenty-four feet of the road bed.

C. After twenty-four hours or more had elapsed to permit penetration, binder bitumens of variable viscosities were applied at the rate of five-tenths gallon per square yard to the center twenty-two feet of the road bed.

D. Immediately following the distributor, the cover aggregate from the road shoulders was bladed over the binder bitumen.

E. The surface thereafter was occasionally bladed to secure uniform distribution of the cover aggregate until it was embedded in the binder bitumen by traffic.

Several interesting conclusions were drawn from this year's work both as to bases and the type of surface treatment.

Because of construction difficulties encountered with the reconstructed type of base stabilization, a base of aggregate and soil binder was considered the most feasible. Further it was concluded that some type of base strengthening was justified.

However, results obtained did not justify any definite conclusions as to types of bitumens used during the year as the cover aggregates used and local conditions encountered were variable for like types of bitumen. However, it was definitely concluded that the construction methods for the ''blotter'' type of surface as used was generally unsatisfactory.

1935 CONSTRUCTION AND DEVELOPMENT

The construction schedules for 1935 were necessarily formulated in the winter of 1934-1935 before many definite conclusions could be drawn from the 1934 construction program.

However, a reconnaissance of all roads to be included in the program was made and disclosed some interesting facts as follows:

A. The amount of surfacing metal **present** on the road surface had no direct relation to the amount of metal which **had been placed** on the road bed, or the length of time that the road had existed in a dry surfaced condition.

B. The depth of surfacing metal on the surface varied from one to two inches in the center and became almost negligible twelve feet from the center line.

C. For roads which had previously been surfaced with bitumen, failures were noted generally on the outer four feet of the center twenty-two foot section but failures, except from frost boils, were rare on the center fourteen feet of the road bed.

D. That base requirements for the state might vary in accordance with soils encountered but should probably be within the limits of four to six inches.

The entire program was scheduled for construction from state funds. Base improvement of the edge strengthening type was scheduled for the entire program with one exception on which a combination of ''edge strengthening'' and ''base stabilization'' was included.

Although the ''blotter type'' of bituminous surface was scheduled for the 1935 program, some important changes were made in the method of construction as follows:

A. Loose material from the road bed was to be bladed or swept over the road shoulders.

B. A definitely graded cover aggregate was specified to be placed by mechanical spreaders at a uniform rate per square yard.

C. The maintenance forces of the highway department to place rollers on completed projects and continue rolling until all aggregate adhered to the binder bitumen.

Although the base work scheduled for 1935 was completed as planned, the bituminous surfacing was confined to resurfacing the work completed in 1934.

Therefore no definite conclusions could be drawn regarding the ''edge strengthening'' method of base work. However, the type of bituminous surfacing specified appeared to be satisfactory except for a few minor alterations in construction details.

1936 CONSTRUCTION AND DEVELOPMENT

The construction program for 1936 contemplated largely the surfacing of roads on which the edges of the subgrade had been strengthened in 1935.

However, two projects included stabilized bases of four inch thickness.

Since it was desired in general to finance this program from Federal Aid funds, it was necessary to secure approval of the Bureau for bituminous surface treatments of the type previously referred to as the "blotter type" and described as to construction details briefly as follows:

A. Clean the road bed of loose material and dust by blades and rotary sweepers.

B. Prime the base at the rate of five-tenths gallon per square yard.

C. Apply three-tenths gallon of binder bitumen and thirty pounds of gravel or crushed rock cover aggregate with mechanical spreaders.

D. Smooth cover aggregate with brush drags, and roll.

E. Apply second application of binder bitumen and cover aggregate at same rate as for first application, drag and roll.

F. After completion of project, maintenance forces to continue dragging and rolling operations until all cover aggregate is imbedded in, or adheres to, binder bitumen.

The Bureau approved bituminous surfaces of this type and the specifications as now drawn are entitled as follows: "Tentative Specifications for Heavy Bituminous Surface Treatments—Inverted Penetration Type."

In general, heavy viscosity binder bitumens were used of the MC-4 and MC-5 and SC-7 and SC-8 grades.

One project with a two inch, road mix mat was completed using tar primer and binder throughout.

1937 CONSTRUCTION AND DEVELOPMENT

The 1937 highway program did not receive official sanction until May of this year, and consequently the bituminous program will necessarily be largely confined to base stabilization. All bituminous work will be financed from state funds which will permit further experimental work without the delays customarily encountered in securing approval by the Bureau of Public Roads.

However, surface treatments will be applied to a small mileage on which stabilized bases were constructed in 1936, and to such 1937 base work as may be completed by the middle of August of this year. Also an additional surface treatment will be applied to previously constructed projects.

The type and class of work scheduled for this year, other than that mentioned in the preceding paragraph, may be briefly outlined as follows:

A. Place a mat surface on one project to permit a study of contemplated improvements in design and construction methods. A revision in the bitumen formula has been made which we hope will more accurately apply to a wide range of bitumen types and takes into account the ''surface area'' factor.

B. Construct soil-aggregate bases of a four inch thickness as the general base type.

C. Construct one experimental base project using subgrade soil mixed with existing surfacing metal and sand in the ratio of twenty-five parts of soil to seventy-five parts of metal, and with tar as the stabilizing agent. Road mix methods will be used.

D. Construct one experimental base project using subgrade soil mixed with existing surfacing metal and sand in the ratio of twenty-five parts of soil to seventy-five parts of metal and with MC bitumen as the stabilizing agent. Road mix methods will be used.

E. Construct one experimental base project using subgrade soil mixed with existing surfacing metal and with Portland cement and SC bitumen as the stabilizing agents. On this project also, road mix methods will be used.

F. Construct one experimental base project of five inch thickness using machine mix methods and of the following types:

(1) Soil-aggregate Base—Conventional soil-aggregate base, one section placed on new grading, and one section placed on a surfaced road bed graded three years ago.

(2) Bituminous Base—Subgrade soil and aggregate mixed approximately 50-50 by weight and using tar as the stabilizer, one section placed on new grading and one section placed on a road bed graded three years ago.

Other bituminous stabilizing agents to be used in a corresponding manner include

(a) MC bitumen (positive)
(b) SC bitumen (both positive and negative)
(c) Emulsified asphalt

(3) Cement soil Base—To be used under conditions similar to that of the bituminous sections except one additional section will be used in which soil and cement only are used.

This project has not been placed under contract at this writing and therefore no other detailed information is available.

All of experimental base projects outlined are for the purpose of establishing practical stabilization methods which might serve as an alternate, on a comparative cost basis, with the conventional soil-aggregate type and possibly one which might be more practical as to construction methods and more serviceable.

CONCLUSION

In conclusion, it may be said that we feel that the solution of a suitable foundation for surface courses, is imperative and rightfully deserves the attention which it is receiving from highway departments all over the nation.

Further than this, we believe, it not unlikely that one solution may be found for heavier traveled routes and another for farm to market and local highways.

We have an opinion that the solution for farm to market and local highways where low cost is imperative may be found as stage development from year to year rather than a single stage solution. However, such possible solutions are now theoretical only and will need practical application before being elaborated upon.

On the premise of current construction practice we favor stage construction for wearing courses from the standpoint of economy of both construction and maintenance.

The following example serves as an illustration of this theory:

A wearing course of the mat type has an assumed life of five years, at the end of which period, it is sufficiently deteriorated to require tearing up and retreating.

A wearing course of the Inverted Penetration Type would require a single course retreatment the third season and again the fifth season, during which time minimum maintenance requirements have existed, and at the end of which time the surface, due to retreatments, is in peak condition.

From a comparative cost standpoint and again assuming a five-year life, with average cost for like work in this state we have:

Mat Construction—2″ Compacted Thickness

Original Construction—1 mile of road mix	
1400 Tons of Aggregate in place on road @ $1.70	$2380.00
4.5% bitumen content, 15,000 gallons @ .075	1125.00
Manipulation, Spreading and Compacting	750.00
Total Original Construction	$4255.00
Retreatment at the end of five years:	
Tear up, and Pulverizing old mat	$ 500.00
2.0% additional bitumen content, 7,000 gal. @ .075	525.00
Manipulating, Spreading and Compacting	750.00
Total Retreatment	$1775.00

Total cost for 5-year period, $4255.00+$1775.00=$6030.00

Surface Treatment—2″ Compacted Thickness

Original Construction—1 mile	
460 Tons of Aggregate in place on road @ $2.25	$1035.00
.6 gallons of binder bitumen, 7744 gal. @ .075	580.80
Manipulation, Spreading and Rolling @ $225.00	225.00
(1″ Thickness)—Total Original Construction	$1840.80
Retreatment one course at end of third and fifth years.	
460 Tons of Aggregate in place on road @ $2.25	$1035.00
.6 gallons of binder bitumen, 7744 gal. @ .075	580.80
Manipulation, Spreading and Rolling (2 operations)	250.00
Total Retreatment (1″ Additional Thickness)	$1865.80

Total cost for 5-year period, $1840.80+$1865.80=$3706.60

The average cost per mile in 1936 for the Heavy Surface

Treatment including binder bitumen, cover aggregate and manipulation was $1753.00.

The approximate thickness of the surface treatment is one inch for double application in original construction, and one-half inch for each additional single treatment or a total thickness of two inches at the end of the five-year period.

A rather extensive research program was begun in the winter of 1936-1937 by the Department of Materials and Tests which is probably more appropriately discussed under the subject of "Fundamentals" and is only briefly mentioned as follows in this paper:

A. Characteristics of primes.

B. Characteristics of various stabilizers for base construction, to include various types of bitumen, emulsions, molasses and Portland cement.

It is believed that the design and construction of bituminous surfaces is so closely associated with research findings, that development in this field is controlled largely by research activities.

It is further believed that development in this field is in its infancy and that the future will reveal possibilities that are as yet, not even anticipated.

Bituminous Concrete Construction

By

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Bituminous concrete construction and the use of the various bitumens cover a wide field. This paper will attempt to deal with this subject only so far as it concerns the Province of New Brunswick, where to date the bitumen used has been confined solely to asphalt.

This province has a total of one thousand, five hundred miles of main trunk roads which it is proposed to pave under our present program. Several factors enter into the decision to use a particular type of pavement, one of the most important being the suitability and availability of aggregates. Some sections have a good quality of stone available while other sections have none.

We have adopted the policy of using local aggregates wherever feasible and our pavement design has been based on the use of these aggregates. By utilizing as much of the local aggregates as are available and which can be incorporated in pavement mixtures, we are enabled to cheapen the cost of this work. To utilize crushed stone for paving aggregates would place too much of a burden on the taxpayers of this province and the bulk of our work will have to be done using gravel aggregates, of which we are fortunate in having quantities available in most sections of the province. The south-eastern section of the province, comprising Westmorland and Kent Counties, has neither rock nor gravel available and any work undertaken in these counties has to be done at a greatly increased cost due to the importation of materials.

The Highway Division of the Department of Public Works in this province has been organized as such on a real working basis only since 1919. The roads of that day were simply trails, grass-grown in a good many spots, and very narrow. Very little gravel had been used on them. From 1919 until the beginning of paving operations an extensive program had been followed year after year of reconstructing the roads and surfacing them with gravel. At the present time nearly all of our main roads are in fair shape except that no attempt has been made to stabilize foundations for pavement surfaces. The roads generally have from three to six inches of gravel and the alignment and grades are fairly good, this work having been taken care of in previous years.

On the more heavily traveled sections of the main trunk highways we have adopted the policy of using a densely graded gravel aggregate of a thickness of three inches consolidated. On the lesser traveled sections of the system we propose using a cheaper type of surface, such as a bituminous carpet coat.

The question may arise as to why we decided to adopt a bituminous concrete base course of only three inches in thickness where other provinces are laying base courses of six or more inches. Our small population of slightly over four hundred thousand has to keep up nearly twelve thousand miles of roads in addition to bridges. The paving of our main trunk roads is quite an undertaking in addition to the maintenance, etc., of the other highways. After taking into consideration the existing traffic and the increase anticipated in future years it was felt that a base course of a thickness of three inches was the minimum we could safely use on the more heavily traveled portions of the main trunk system, having regard to our subgrade conditions. A pavement width of twenty feet was adopted as standard.

We recognize that probably the most important work to be done is the stabilization of the sub-grade previous to putting any wearing surface on it. This we are doing by means of a system of tile underdrains in addition to heavy side ditches outside the roadbed proper. This enables us to lower the water-table in the sub-grade and to help control, with the addition of gravel sub-base immediately under the pavement, the action of capillary water.

New Brunswick's paving program was started in 1930 by the passing of an act by the Legislative Assembly voting ten million dollars for this work, to be spread over a period of five years. This act was not put in force until the summer of 1934 when seven contracts were let for sixty-six miles of paving. This work was started late in the summer of 1934 and only about fifteen miles of pavement were completed at the end of the season's operations.

In the spring of 1935 eight more contracts, totaling seventy miles, were awarded. The remainder of the 1934 contracts and all the 1935 contracts were completed at the end of the 1935 season.

These contracts were for paving only. During 1934 and 1935 practically all of the preparatory work, embracing the installation of tile underdrains, the addition of gravel sub-base, and the renewing of culverts, structures, etc., was undertaken by the Department's own forces at day's work.

The contracts comprising the 1934 operations were generally in very good shape, requiring very little work other than the installation of tile underdrains. These sections had been rebuilt within a few years and consequently were up to our standard of construction.

The 1935 contracts had to have more work done on them The ditches were cleaned and the road widened slightly, in addition to the installation of the underdrainage system. This work was also carried out by departmental forces on a day's work basis.

Realizing that the reconstruction work necessary to realign our roads and reduce grades should be done at least a year in advance, we decided for the 1936 operations to call for both grading and paving in the one contract and to allow the work to go over a period of two years. We proposed to concentrate during the season of 1936 on the grading end of the contract more particularly, with the idea of getting at least seventy-five percent of the grading completed at the end of the 1936 season, with possibly about twenty-five percent of the pavement completed. This will allow the bulk of the grading to season over the winter. During 1937 any grading left to be done on any contract will be completed, together with the rest of the pavement.

PREPARATORY WORK

With the beginning of the paving program it became absolutely essential that the foundation be stabilized, and to do this we adopted the system of tiling wherever necessary. The points for tile installation have been determined by spring surveys of frost conditions, extending over a two or three-year period.

Several systems have been tried in connection with tiling and the one favored at the present time is the use of longitudinal side-drains immediately outside the pavement edge. Some cases call for, especially on side-hill work, the tile to be placed on the high side, thus cutting off the seepage of under-ground water from the side-hill. Other sections have two side longitudinal drains while others call for a centre-line longitudinal drain with laterals leading into the main.

These trenches are dug to a minimum of four feet in depth and are laid to a minimum grade of three inches to one hundred feet. Suitable offtakes are provided at intervals and in every case the tile drain must have an outlet even if it entails excavation of from six to eight feet in depth. The trench is excavated about eighteen inches in width. The tile is bedded in three inches of coarse gravel or crushed stone, ranging in size from one-quarter inch to two and one-half inches. This is thoroughly tamped. The tile is laid on this bottom course, the joints being as tight as practicable and the upper half being covered with strips of tar paper. Crushed stone or gravel of the sizes above specified is then filled about the pipe and over it for a depth of six inches, all carefully tamped without displacing the pipe or joint covering. The remainder of the trench is then backfilled with coarse gravel or broken stone, ranging in size from one-quarter inch to four inches. This backfill is carefully tamped in layers not exceeding nine inches in thickness.

Our specifications call for agricultural tile, cement concrete tile, or perforated corrugated iron pipe. To date we have used only the agricultural tile with very good satisfaction, laying over five hundred thousand lineal feet of this material.

After the installation of the tile underdrain the grading of the sub-grade is proceeded with. Gravel sub-base of a thickness of four inches consolidated is laid on the freshly graded sub-grade and traffic consolidated. This is the complete grading operation.

As soon as the sub-grade is considered fit for paving the necessary fine grading is done by the Contractor, the gravel sub-base primed and allowed under traffic for at least a week, when paving operations may start. New culverts and structures, of course, are proceeded with, along with the grading operations.

During 1934 and 1935 upheavals and depressions developed in the pavement over certain of our culverts. These have had to be relaid in several cases. This year we are calling for complete gravel backfill to be used around all culvert pipes.

The culvert is bedded in gravel, and gravel at least a foot in thickness is carried up the side of the culvert to three feet over the top. By this means we hope to minimize the movement in the pavement over these culverts.

This year we are also utilizing a good many box culverts made of from six to eight inches square, creosoted hardwood timber. These structures are backfilled with gravel the same as the culvert pipe.

DESIGN OF PAVEMENT

The 1934 contracts were awarded on the following basis: Four consisted of crushed stone for aggregate, and three of crushed gravel. The base course consisted of a thickness of 3 in. consolidated with a wearing surface of one-inch sheet asphalt. All of these were hot mixed.

The coarse aggregate met the following specifications:

Crushed Gravel:

Passing	Per Cent
1½-in. screen	100
¾-in. screen	25-75
¼-in. screen	not more than 5

Crushed Stone:

Passing	Per Cent
2 -in. screen	100
1 -in. screen	25-75
¼-in. screen	not more than 5

The fine aggregate met the following specifications and was the same for either crushed gravel or crushed stone:

Passing	Retained On	Per Cent
¼-in. screen	....	100
¼-in. screen	10-mesh sieve	8-25
10-mesh sieve	40-mesh sieve	15-50
40-mesh sieve	80-mesh sieve	22-65
80-mesh sieve	200-mesh sieve	7-40
200-mesh sieve	....	0- 8

The mineral filler used in the sheet asphalt wearing surface consisted of thoroughly dry limestone dust and met the following requirements:

Passing	Per Cent
30-mesh sieve	100
100-mesh sieve	not less than 85
200-mesh sieve	not less than 65

The constituents of the base and surface mixtures using crushed gravel were combined in such proportions to produce mixtures conforming, by weight, to the following composition limits:

Passing	Held On	Asphaltic Concrete Per Cent	Sheet Asphalt Per Cent
1½-in.	¾-in.	20-40	none
¾-in.	¼-in.	20-40	none
¼-in.	50-mesh	10-25	25-45
50-mesh	200-mesh	15-35	20-40
200-mesh	....	0- 8	10-20
Bitumen	....	4- 7	9.5-12
Total	....	100	100

The constituents of the base and surface mixtures using crushed stone were combined in such proportions to produce mixtures conforming, by weight, to the following composition limits:

Passing	Held On	Asphaltic Concrete Per cent	Sheet Asphalt Per Cent
2-in.	1-in.	10-35	none
1-in.	¼-in.	30-50	none
¼-in.	50-mesh	10-25	25-45
50-mesh	200-mesh	15-35	20-40
200-mesh	....	0- 8	10-20
Bitumen	....	4- 6	9.5-12
Total	....	100	100

Specifications for the asphalt cement were as follows:

The asphalt cement shall be homogeneous and free from water and shall not foam when heated to 175° C. (347° F.)

(a) Flash point, open cup, not less than 175° C. (347° F.)

(b) Penetration at 25°C. (77°F.) 100 g., 5 sec., 71-80
(c) Ductility at 25°C. (77°F.) not less than 100
(d) Loss at 163°C. (325°F.) 5 hours, not more than 5 per cent
Penetration of residue at 25°C. (77°F.) 100 g., 5 sec. as per cent of original penetration, not less than 50 per cent
(e) Proportion of bitumen soluble in tetrachloride, not less than 99 per cent

The formula for the mixture using crushed gravel or crushed stone as the aggregate was substantially as follows:

Materials	Asphaltic Concrete Per cent	Sheet Asphalt Per Cent
Coarse, held on 8-mesh	55	none
Fine, passing 8-mesh	40	70
Mineral filler	none	20
Asphalt cement	5.5	10
Total mixture	100	100

The 1935 contracts were let on the basis of five jobs using crushed gravel and three using crushed stone.

The coarse aggregate composed of crushed gravel met the following requirements:

Passing	Per cent
1¼-in. square screen	100
¾-in. square screen	45-75
4-mesh sieve	not more than 5

The coarse aggregate using crushed stone was the same as the above except that all the material passed 1½ in. square screen.

The fine aggregate used with either crushed gravel or crushed stone met the following requirements:

Passing	Retained On	Per Cent
4-mesh sieve		100
4-mesh sieve	16-mesh sieve	5-20
16-mesh sieve	50-mesh sieve	25-40
50-mesh sieve	200-mesh sieve	20-40
200-mesh sieve		0- 8

The mineral filler used in the sheet asphalt wearing surface was the same as for the 1934 contracts.

The constituents of the base and surface mixtures using crushed gravel were combined in such proportions to produce mixtures conforming, by weight, to the following composition limits:

Passing	Held On	Asphaltic Concrete Per Cent	Sheet Asphalt Per Cent
1½-in.	¾-in.	15-30	none
¾-in.	4-mesh	25-40	none
4-mesh	50-mesh	25-40	30-55
50-mesh	200-mesh	6-15	20-40
200-mesh	....	0- 8	12-25
Bitumen	....	4- 6	8.5-11
Total	....	100	100

The constituents of the base and surface mixtures using crushed stone were combined in such proportions to produce mixtures conforming, by weight, to the following composition limits:

Passing	Held On	Asphaltic Concrete Per Cent	Sheet Asphalt Per Cent
1½-in.	¾-in.	20-30	none
¾-in.	4-mesh	25-40	none
4-mesh	50-mesh	25-40	30-55
50-mesh	200-mesh	6-15	20-40
200-mesh	....	0- 8	12-25
Bitumen	....	4- 6	8.5-11
Total	....	100	100

The specifications for the asphalt cement were the same as those used for the 1934 contracts.

The formula for the mixtures using crushed gravel as the aggregate was substantially as follows:

Materials	Asphaltic Concrete Per Cent	Sheet Asphalt Per Cent
Coarse, held on 8-mesh	65	none
Fine, passing 8-mesh	30	70
Mineral filler	none	20
Asphalt Cement	5	10
Total Mixture	100	100

The formula for the crushed stone aggregate was the same as the above except that the coarse material for the asphaltic concrete was 60 instead of 65 per cent, and the fine material for the asphaltic concrete was 35 instead of 30 per cent.

During July, 1935, the Provincial Government decided to make a change in the wearing surface applied to the base course on several of the contracts. Instead of the 1-in. sheet asphalt surface being used a plant mixed surface seal course was substituted and this was applied to the base course at the rate of from 15 to 30 lbs. per sq. yd. The amount actually used was in the vicinity of the top limit.

Due to the fact that this surface seal course was a very much thinner wearing surface the grading of the coarse and fine aggregates was changed to make a more closely textured base course. The coarse aggregate then met the following grading requirements:

Passing	Per Cent
1¼-in. screen	100
1-in. screen	90-100
¾-in. screen	55- 75
4-mesh sieve	not more than 5

The fine aggregate met the following grading requirements:

Passing	Held On	Per Cent
4-mesh	....	100
4-mesh	16-mesh	10-35
16-mesh	50-mesh	25-40
50-mesh	200-mesh	15-35
200-mesh	....	5-20

No mineral filler was used in the surface seal course, the percentage of material passing 200-mesh being stepped up to give the required density.

The constituents of the base and seal course mixtures were combined in such proportions to produce mixtures conforming, by weight, to the following composition limits:

Passing	Held On	Asphaltic Concrete Per Cent	Seal Course Mixture Per Cent
1¼-in.	¾-in.	15-25	none
¾-in.	4-mesh	25-40	none
4-mesh	50-mesh	25-40	30-55
50-mesh	200-mesh	6-15	15-35
200-mesh	....	2- 8	4-18
Bitumen	....	4- 6	8.5-12
Total	....	100	100

No change was made in the asphalt cement specifications.

During 1934 and 1935 the one-inch sheet asphalt wearing course was usually applied to the base course the following day. When the surface seal course mixture was adopted the method of laying the top on the base was changed. The surface seal course was applied to the base before it became chilled. The surface course was sent out from the plant as hot as possible and broadcast on the still warm base course by means of shovelers and immediately rolled, thus becoming a homogeneous part of the base course with a compacted thickness varying from one-eighth to one-quarter of an inch. This seal course could not be bonded properly to the base unless this method was adopted.

All plants used in manufacturing paving mixtures were and are of the batch type of a size approved by the Engineer and are provided with separate chambers for heating and mixing the constituents.

The coarse aggregate and sand are dried and heated in an approved type of revolving drier equipped with a registering pyrometer at the discharge chute.

After leaving the drier, all hot aggregate is passed over a screen so as to separate it into not less than two sizes. Each bin compartment is equipped with a discharge gate directly over the weighing hopper.

The weighing hopper has sufficient capacity to hold the maximum amount of aggregate for one batch.

Scales may be either of the dial or beam type, but if of the beam type must be equipped with a precision indicator.

The asphalt bucket for weighing the asphalt cement has sufficient capacity to hold not less than twelve per cent of the weight of aggregate required for one batch and it must be suspended on dial scales.

All plant scales, including truck scales, are tested periodically by the proper authority.

Melting kettles and hot storage tanks which deliver asphalt directly to the weigh bucket are equipped with thermometers and means for positive control of asphalt temperatures at all times.

The mixer is of the twin shaft pugmill type.

During 1934 and 1935 the asphalt cement was heated at the paving plant to a temperature of from two hundred and fifty to three hundred and fifty degrees Fahrenheit.

The coarse and fine aggregates comprising the base course were dried and heated so that when delivered to the mixer they were at a temperature of from two hundred and fifty to four hundred degrees Fahrenheit, and on arrival on the road at a temperature of from two hundred and fifty to three hundred and seventy-five degrees Fahrenheit.

The fine aggregates for the sheet asphalt were delivered to the mixer at a temperature of from three hundred to four hundred and fifty degrees Fahrenheit, and on the road at a temperature of from two hundred and seventy-five to four hundred and twenty-five degrees Fahrenheit.

The fine aggregates for the surface seal course were delivered to the mixer at a temperature of from two hundred and fifty to four hundred degrees Fahrenheit and arrived on the road at a temperature of from two hundred and fifty to three hundred and fifty degrees Fahrenheit.

This spring the Department called for tenders for fourteen different contracts comprising three hundred and thirty-two miles of bituminous concrete pavement and eighty-nine miles of bituminous carpet coat.

Several radical changes were made in the specifications covering the work for this year and 1937, contracts being on a two-year basis, concentrating as mentioned before on the grading during this year and on the pavement during 1937.

The amount of gravel sub-base placed upon the prepared subgrade and beneath the pavement was increased slightly over preceding years so that we require now a gravel sub-base of a minimum of four inches consolidated. This material is consolidated by traffic and immediately before the pavement is placed any necessary fine grading is done and this sub-base material is primed. During 1934 and 1935 no priming whatever was done.

The following is the specification for the asphalt primer:

(a)	It shall be homogeneous and free from water.	
(b)	Specific gravity at 60 deg. Fah., not less than	.975
(c)	Flash point, open cup, deg. Fah., not less than	90
(d)	Viscosity at 122 deg. Fah. (Saybolt Furol), sec	15-20
(e)	Distillation (A.S.T.M. Method D402-34T)	
	Per-cent recovery by volume:	
	At 374 deg. Fah., not less than	4
	At 437 deg. Fah., not less than	11
	At 500 deg. Fah., not less than	19
	Total recovery at 680 deg. Fah., not more than	40
	Distillation Residue:	
	Per-cent by weight, not less than	66
	Softening point (B. & R.) deg. Fah., not less than	100
	Penetration at 77 deg. Fah., 100 g., 5 sec., not more than	200
	Ductility at 77 deg. Fah., cms., not less than	100
	Solubility at air temperature in CS_2, per-cent, not less than	99.5

The primer is applied to the sub-base material by means of an approved pressure distributor at a rate of not less than one-quarter nor more than one-half an imperial gallon per square yard at a temperature of not less than sixty nor more than one hundred and twenty degrees Fahrenheit.

The tank wagons, trucks, and distributors used for the transportation or application of asphalt primer are equipped with satisfactory thermometers for registering the temperature of the material to be applied.

The thickness of the base course being used at the present time is still three inches consolidated and is composed solely of crushed gravel as a coarse aggregate.

The plant mixed surface seal course is being used and is applied at the rate of from thirty to forty pounds per square yard.

The gravel used as coarse aggregate must contain approximately fifty per cent of crushed particles and must be washed if necessary.

The fine aggregate, composed of natural sand or crushed particles of the gravel, meets the following grading requirements:

Passing	Per Cent
4-mesh	95-100
30-mesh	30- 55
100-mesh	15- 35
200-mesh	6- 25

The coarse and fine aggregates specified above are combined in such proportions to produce an aggregate graded within the following limits:

Passing	Per Cent
1¼-in. round	100
¾-in. square	75-90
⅜-in. square	55-75
4-mesh	40-60
30-mesh	15-30
100-mesh	7-18
200-mesh	3-14
Total	100

The constituents of the bituminous concrete and seal course mixtures are combined in such proportions to produce mixtures conforming, by weight, to the following composition limits:

	Asphaltic Concrete Per Cent	Surface Seal Per Cent
Coarse aggregate	40-60	....
Fine aggregate	35-55	89-93
Bitumen	4- 6	7-11
Liquefier	0- 1¼	0- 2

The asphalt cement in use this year is much softer than that used in previous years and is used in both the asphaltic concrete base course and in the asphaltic surface seal course.

It conforms in all respects to the following specifications:

It shall be homogeneous and free from water, and shall not foam when heated to 175 deg. Cen. (347 deg. Fah.).

(a)	Specific gravity at 60° F., not less than	1.00
(b)	Flash point, open cup, not less than	300° F.
(c)	Softening point (B and R)	80-100° F.
(d)	Volatility at 325° F., 50 grams, 5 hours, per cent loss by weight, not more than	1.0
(e)	Ductility: When the material is evaporated to 100 penetration residue, this residue shall have a ductility	
	At 77° F., 5 cms. per minute, of not less than	100 cms.
	At 39° F., 1 cm. per minute, of not less than	6 cms.
(f)	Solubility at air temperature in CS_2, per cent, not less than	99.5

This year we introduced a new departure by permitting the use of a liquefier to permit shipments of mixed material by rail. This allows the use of a central mixing plant where one Contractor has bid in two jobs, or where the haul from his plant set-up is not economically feasible by truck.

This liquefier is added to the aggregate in the mixer box after the asphalt cement has been put in. Tests which we have conducted show that this material can be spread without any difficulty a week or ten days after it is mixed.

The liquefier meets the following specifications:

This material is to be homogeneous and free from water.

Initial boiling point	200 deg. Fah.
Final boiling point	500 deg. Fah.

This material is to be a petroleum distillate made from a source which shall result in the highest solvent power for the solid asphalt as supplied.

To meet local conditions the refinery shall be required to produce this material within a 200 deg. Fah. boiling point range as specified by the engineer.

The type of plant used for mixing pavement mixtures is the same as formerly used.

The asphalt cement is heated at the paving plant to a temperature of from one hundred and fifty to two hundred and twenty-five degrees Fahrenheit.

The coarse and fine aggregates are dried and heated at the paving plant and delivered to the mixer at a temperature of from one hundred and seventy-five to two hundred and fifty degrees Fahrenheit.

Without wishing to enter into any argument as regards the merits of a plant mixed surface seal course as against a liquid asphalt seal coat, it might be advisable to state the reasons for using this particular type of seal coat. The sand used in our plant mixed surface seal is composed of identically the same aggregate as is used with the coarse aggregate to make the base course. The material is simply drawn from the required bin when needed and the proper proportion of asphalt cement added. It is then taken out and placed on the road.

In using a liquid seal the cover coat used should be composed of very hard, sound chips in order to get the best results. This material is not very plentiful in our province and would entail a greatly increased cost to the seal coat if it were used. We are also of the opinion that the life of the plant mixed seal coat is considerably longer than that of the liquid seal, thus effecting an appreciable saving in maintenance cost.

CONSTRUCTION

Our paving mixtures have always been transported from the paving plant to the work in clean, tight vehicles and where necessary these vehicles are covered with canvas or other suitable material to protect the load from weather conditions.

During 1934 and 1935 we allowed the use of hand work spreading the paving mixtures, together with the use of spreading and finishing machines. The majority of the Contractors used the ordinary spreading box, finishing the surface with hand rakers.

We found that the use of the spreader box alone plus rakers did not give us as good results as the spreading machine, due to the fact that in spite of all precautions, segregation of material in the pavements surface resulted from the use of hand work. This year our specifications call for the use of self-propelled spreading and finishing machines, or an approved spreading machine which is towed by a truck. The use of the spreader box alone with hand work is not allowed.

After the spreading machine has passed, the surface of the mixture has to be smooth and true to cross section, free from all hollows, irregularities, and segregated areas, and of a uniform density throughout.

The placing of the pavement mixtures is as continuous as possible. Where traffic is not diverted from the section under construction the pavement is laid in two strips, each one-half the full width of the pavement, the two strips being carried forward in alternate stretches as close together as possible in order that the material of the second strip may be bonded to that of the first along the centre line of the pavement, thus preserving the proper bond and contour of the whole.

Immediately after spreading, for this year's work, the base course is given a preliminary rolling with a power-driven tandem roller. We did not specify the weight of this roller but thought that probably the best job would be obtained by using a roller weighing from five to eight tons, giving the base course a light initial compaction just previous to spreading the surface course.

During 1934 and 1935 the initial rolling of the base course was done with a three-wheel roller of not less than ten tons in weight and the pavement finished with at least a ten-ton tandem roller. The same applied to the sheet asphalt wearing surface, the break-down being done by means of the three-wheel roller and the finishing with the tandem.

The surface seal course this year is spread as soon as possible after the base course has been given the preliminary rolling. The amount is at the rate of from thirty to forty pounds per square yard, spread by means of shovelers broadcasting over the base. Lutes or rakes are being used to smooth it up. Immediately following the spreading of the surface seal course the rolling is continued with a power-driven, three-wheel roller weighing not less than ten tons. We are not permitting traffic over the base course or the seal course until it has had a preliminary rolling.

Side forms have always been used by us with all types of bituminous concrete pavement and they are again specified for this year.

Another difference made in this year's operations over preceding ones is that we are rolling at least part of the shoulder material with the final rolling or consolidation of the pavement. This entails the Contractor's removing his forms and placing at least part of his shoulder material previous to the final rolling. The final rolling may not take place for two or three days after the initial rolling. The rolling is continued from day to day until there is no displacement of the surface. We are limiting rolling to a rate not in excess of twenty tons per hour, per roller.

The surface of the finished pavement shall be smooth and true to the established crown and grade and shall present a surface of uniform texture with no evidence of segregation or insufficiently sealed areas. Its average thickness shall be from three and one-tenth to three and one-quarter inches and shall at no point be less than two and seven-eighths inches in thickness. The surface must be free from depressions exceeding one-quarter of an inch, as measured with a ten-foot straight edge paralleling the centre line of the roadway.

Payment is made to the Contractor on a tonnage basis for both the base and seal courses and the Contractor is obliged to provide and install an approved truck scale at a location convenient to the asphalt plant. The Department provides a weighing checker for this material.

FIELD ORGANIZATION

Each contract is in charge of a Resident Engineer who has one or more instrumentmen and the necessary assistants to take care of the laying out of the work. The checkers are supplied by the Department and are under the control of the Resident Engineer.

Each job has two inspectors; a Road Inspector, who is responsible for the laying of the pavement mixtures; and a Plant Inspector, who is in charge of the plant operations.

The Plant Inspector's chief duties are to see that the proper amount of bitumen is added to the mixtures according to the grading. Samples of these mixtures are taken periodically and sent to Montreal where they are analyzed for both grading and bitumen content to see that they conform in all respects to our specifications.

In addition to the Plant and Road Inspectors, the Inspection Company supplies one or more supervisors who are traveling back and forth constantly between the jobs, advising and correcting where necessary.

The inspectors are under the joint supervision of the Resident Engineer and the Paving Director, through the supervisors of the Inspection Company.

The Resident Engineers and Inspection Staff are under the supervision of one or more Inspecting Engineers, reporting directly to the Chief Highway Engineer or the Assistant Chief Highway Engineer.

COSTS

The approximate average cost per mile of pavement, including preparatory work, using a one-inch sheet asphalt wearing surface, in 1934 and 1935 was nineteen thousand dollars. The approximate average cost per mile of pavement, including preparatory work using the plant mixed surface seal course, in 1935 was seventeen thousand dollars. The estimated cost per mile, complete, of our 1936-1937 bituminous concrete paving program is seventeen thousand, five hundred dollars. This is slightly higher than the cost immediately preceding but is due to the fact that this year's program includes the cost of heavy grading on all jobs, which was not necessary during 1934 and 1935.

During 1934 and 1935 our contracts varied in length from seven to twelve miles, for 1936 and 1937 from twenty-five to thirty-five miles.

One of the main reasons for lengthening the contracts was that we would be able to get much better prices from the Contractors and this would effect a very appreciable saving in our final cost. We also thought that by embodying the grading in the various contracts, instead of using departmental forces for this work, we could save still further.

As soon as possible we hope to have the sources of all aggregates determined for all future jobs. These would be tested and approved before tenders were called for a contract, so that the Contractor would be in a position to know definitely just where the various aggregates were to be obtained. This would tend to lower unit prices considerably. Up to date we have not been able to do this and there has been a certain amount of guess work on the Contractor's part as to whether aggregates he proposes to use would, in the final analysis, be acceptable to the Department.

On the whole, the pavement laid during 1934 and 1935 has come through to the present time in a very satisfactory condition. We have had a certain amount of cracking which is being taken care of by our maintenance crews.

One of the main reasons for adopting the soft type of asphalt this year was that we felt that its use would minimize the amount of cracking which has taken place in the pavement when using a harder type of paving asphalt. New Brunswick's soil and climatic conditions are such that it is almost impossible to get away altogether from a certain amount of frost action in the foundation of the road, no matter how careful we are with our preparatory work and system of tile underdrains. We felt that the use of this softer type of asphalt would allow for a more flexible pavement and one which would give more readily under the action of frost.

This paper naturally has had to be condensed and a great deal of the detailed construction of this type of pavement has been left out. If anybody interested applies to us at Fredericton, we shall be only too glad to forward any or all of our specifications.

Developments in Practical Design and Construction of Bituminous Surfaces

By

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In order to discuss developments in design and construction of bituminous surfaces in Wyoming, it will be necessary to also discuss the developments of base courses on which the bituminous mats have been constructed, and this may overlap the discussion by others on "The Developments of Fundamentals of Bituminous Construction."

The older gravel base courses already built or under construction at the time the first oil mats were laid, consisted of a trench section, 18 or 20 feet wide and having an average thickness of 6 inches, leaving an earth shoulder 2 or 3 feet in width on each side of the gravel section. On account of maintenance and both wind erosion, and erosion under traffic, these gravel surfaces gradually decreased in thickness, varying according to the amount of traffic, location in the state and the kind of material used in their construction. As late as 1927 it was still the intention of the Highway Commission to bring the entire State Highway System to a gravel surface standard by the year 1938, a ten-year period being considered necessary for this purpose.

About this time however, much concern was manifest on account of the great loss of surfacing material for the reasons above stated and it was seen that it would be necessary to renew or replenish the gravel surface courses every few years, greatly increasing the cost of maintenance of the roads besides depleting the supplies of gravel surfacing material, already becoming scarce in some localities. This prompted investigation into other methods of constructing road surfaces that would be of a more permanent nature, as well as to provide a better and less dusty surface. With the increasing amount of traffic it was becoming very expensive and difficult to maintain the gravel surfaces and the dust menace was always with us.

After some experimental work in 1927, several projects of road oiling were placed under construction in 1928 during which year about 85 miles of road mixed surface were constructed. Up to 1931 all oil work was done by State forces using available maintenance equipment. Beginning in 1931 most of the work was let to contract and has continued in that manner up to the present time. At the beginning of the present year the mileage of bituminous surfaced roads in Wyoming amounted to 2630 miles or 72% of the entire state system. Projects under contract at this time will increase the amount of such surfaces to 3000 miles.

Early mats were mostly built to a thickness of 3 inches and having a width of 20 feet. Asphaltic material used was 60-70 road oil corresponding to the present SC-2 specification, later changed to 70-75 grade, similar to the present SC-3 and to 75-80 for plant mix work. The aggregate for the mats was obtained by scarifying the old base. On account of loss of material since time of placing of the gravel surfacing, the amount of base course remaining was variable, in some cases practically all the surfacing was used in construction of the oiled mat. Under these conditions, placing bituminous mats on the old road beds, many with poor drainage conditions, lack of base course and earth shoulders, it is easy to understand why there were some failures in these early projects. However, many of these early jobs are still in good condition after years of service, this being attributed to the dry, arid condition of a great part of Wyoming.

It was found that practically all the failures of the mats were along the shoulders, the reason being very apparent on account of lack of base course surfacing at that point, and also on account of the method of construction of the edges of the mats, many of which were feather edged.

On later work, gravel base courses were increased in thickness, new aggregate supplied for construction of the mats and gravel shoulders added after construction, these things together with better construction of the sub-grades and having adequate drainage, all of which tended to provide better surfaces and also decrease the cost of maintenance.

Present practice in Wyoming takes into consideration the kinds of soils used in construction of all the sub-grades and adequate drainage and the kind and amount of base course material varies as to the conditions.

Where it is considered necessary heavy sub-bases are placed, while in many places, thin base courses are considered sufficient, in some even no base course is needed as the entire sub-grade may be of suitable material to serve as a base course. In many sections we are placing 6 to 12 inches of pit run gravel, on which is placed a cushion course of crushed material, both stabilized by the use of binder and water then thoroughly rolled to completion. All base courses are placed full width of the road bed. Prime coat using ⅓ to ½ gallon of MC-1 is applied and allowed to set up before construction of the mat. On the lighter traffic roads mats are being built to a thickness of 1½ inch but 2½ inch mats are being constructed on the heavy traffic routes. Gravel shoulders are being placed and rolled after construction of the wearing surfaces and seal coat using RC-2 applied after the mat has been turned over to traffic for some time. Where considered necessary on account of traffic, the seal coat is sanded at time of application.

The trend in Wyoming the past two years has been to the use of cut-backs, starting in 1935 with some use of MC-2 and changing during the past year to MC-3. The writer is of the opinion that more stable roads will result from the use of the cut-back material, believing that more resistance is offered to the action of water on the mat than is obtained from the SC- products and decreasing the amount of maintenance necessary to keep the surfaces in condition. The writer believes that although the initial cost of construction with the use of cut-back is considerably greater that they will provide a better cheaper surface over a long period. However, as the roads constructed in this state by the use of MC- cut-backs have been in service less than two years we have not had sufficient time to make proper comparisons. Many of our roads constructed with SC material are still in fine shape and there is considerable agitation for the return to the use of SC-3 or SC-4, especially on roads situated where soil and drainage conditions are exceptional.

Considerable trouble has been experienced in the use of MC-3 by the road mix method at the higher elevations in Wyoming, and there is a question of the use of MC-2 for that purpose or whether the mountain roads should be built by use of the plant mix method.

Equipment used in the construction of bituminous surfaces in Wyoming is probably the same as used generally for this purpose. Most of the work is done by the use of road mix machines, the Woods, Barber-Greene and Cedar Rapids machines all being used successfully, although the Wyoming Specifications require that the material be thoroughly mixed by blade graders after coming through the machine. After thorough mixing the material is laid down and rolled with a 5 to 10 ton roller.

CONCLUSION

Late developments in the construction of bituminous surfaces have been more in the construction of the sub-grades and base courses for the bituminous surface than in the construction of the surface itself and as we all agree that the mats can only be as good as the foundation, the improvements have been shown to be in the right direction. With a properly constructed sub-grade using only suitable material, properly drained and having an adequate base course, all thoroughly compacted, there seems no reason why the bituminous mat should not be satisfactory and serviceable.

As to the question of the proper grade of material to be used, whether SC, MC or RC, there probably will always be some difference of opinion but no doubt there is the proper place for each of them, according to whether the location is wet or arid, the amount of traffic and the kind and grading of the material to be used as aggregates in the wearing surfaces.

As I see it our greatest development in Wyoming has been the construction of better sub-grades and the use of water and binder in producing thoroughly compacted smooth base courses on which to construct the bituminous surfaces, as our methods of constructing the mats itself have not changed materially except in the kind of bituminous material used and where proper bases were constructed in conjunction with the bituminous surface, excellent results are evident with the use of both SC and MC materials. With the wider roadbeds, somewhat wider mats, with a good base course under the edges of the mat particularly, and gravel shoulders, most of our former trouble has been eliminated. There still remains the problem of construction of the mats themselves in being sure that mixed aggregates and base are dry at the time the material is laid down, but this is a matter of good inspection and whether a good job is secured or not still depends on the Inspector, the man on the job. With the fine cooperation furnished by the Materials Engineer and the laboratory, much of the guess work has been taken off the shoulders of the man in the field but good inspection and management of the field work still remains the important phase in the construction of bituminous mats.

Development in Practical Design and Construction of Bituminous Mat Surfaces in Kansas

By

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The subject "Development in Practical Design and Construction of Bituminous Mat Surfaces in Kansas" as outlined below, will of course be based on many theories and ideas which will undoubtedly conflict with those held by many reputable engineers. It is not my intention to intimate in any way that theories or ideas conflicting with those contained herein are wrong, and I solicit and will welcome evidence that those contained in this paper are incorrect. The opinions stated herein are the results of seven (7) years study and observation of bituminous surfaces from both the engineering and contracting sides, and are those upon which Kansas will design and construct its bituminous surfaces this fiscal year, unless new and additional information should warrant changes.

DESIGN

Engineering at this date has progressed to the point where it is generally agreed that no highway surfacing should be placed on an inadequate base. Therefore, our first problem is to determine what is an adequate base. The factors needed to determine this are: (1) Type of soil in base. (2) Will ample drainage be provided? (3) Annual rainfall. (4) Annual temperature changes. (5) Amount of traffic. (6) Type of traffic. (7) Type and approximate thickness of the surfacing. Explanation and use of above factors are as follows:

(1) Type of soil is the first consideration as almost every phase of design is affected by the composition of the soil base. After the soil has been classified its load carrying capacity should be determined at the optimum moisture content as well as at the highest and lowest moisture content it can reasonably be expected to have throughout its life in the road bed.

In Kansas most soils west of Highway U.S. 81 are loams in which the sand and silt fractions predominate. (A2, A4 and A4-7 groups) and these with good drainage can be expected to carry present day traffic, without treatment, except for some unusual spot where seepage occurs due to rock or shale ledge outcrop in the base. Where such outcrops occur various common types of drains such as pipe, crushed rock, or both, may be installed. East of Highway U.S. 81, which is about the eastern half of the state, soils are largely clay loams and clays in which the clay fraction predominates. Here major parts of the soils are of the A4, A4-6, A4-7, A6 and A7 groups and become more difficult to drain and stabilize. (Stabilization Methods as outlined in another paper entitled "Bituminous Mat Development in Kansas.")

(2) Proper drainage is very important because, in many cases, it will replace the need for stabilization, especially where roadway width is ample to permit the ditch bottom to be far enough from shoulder of the road bed, so that the moisture, attempting to travel from the free water in the ditch to subgrade under the mat will be lost to a large extent by evaporation or used up by vegetation. Therefore, shoulder slopes should be at least 6:1, or the road constructed with a ten foot berm between the ditch and the road bed, the natural ground line being the berm where possible.

The above described sections also offer much in the way of safety to the traveling public. Laboratory tests of model sections of the above have shown interesting results in the matter of protecting the subgrade from excessive moisture.

(3) Rainfall in the western half of the state varies from 9

inches to 25 inches and in the eastern half from 25 inches to 40 inches. This variation tends to increase, in Kansas, the difficulty encountered with the heavy soils of the eastern portion.

(4) In the western half of the state very little moisture falls during freezing weather. Therefore, frost boils are uncommon, but in the eastern half conditions are more favorable for frost boils and must be given more consideration in subgrade treatment.

(5) Traffic count is much lower in the west, running from 150 to 1500 vehicles per day on more important highways.

(6) Some of our highways have a very high per cent of truck traffic due to oil fields and transportation of gas to northern Kansas and Nebraska. (Lack of good railroad connections and economy of transportation have caused the growth of this type of traffic).

(7) It is believed that any bituminous mat under 2 inches in thickness should not be expected to help distribute the weight of the traffic over the base but that the subgrade should be designed to carry all of the load as if it were to be applied directly to the subgrade.

With the above factors properly considered the design of the mat should be given next consideration. No bituminous mat should contain less than 1200 tons of aggregate per mile and 1500 or even 2000 tons per mile is to be preferred, with a minimum width of finished mat of 24 feet. Aggregate in all cases should be densely graded and may consist of crushed stone, gravel, or chat with limestone dust, silt, volcanic ash or chat sludge added for filler. Often a combination of crushed stone and sand-gravel or sand-gravel, chat and filler material will give a more dense aggregate. The following are standard specifications for densely graded aggregates:

Retained on 1-inch mesh sieve	0%
Retained on ⅜-inch mesh sieve, from	15% to 30%
Retained on 8 mesh sieve	25% to 50%
Retained on 30 mesh sieve, not more than	75%
Passing 200 mesh sieve, from	8% to 15%

Retained on 1½-inch mesh sieve	0%
Retained on 1-inch mesh sieve	0 to 5%
Retained on ¾-inch mesh sieve	10 to 30%
Retained on 4 mesh sieve	30 to 50%
Retained on 30 mesh sieve	60 to 80%
Passing 200 mesh sieve	5 to 10%

Every thought should be given to the development of a mat with the least amount of voids practicable. This will help exclude water and air. It is thought that if water and air, which are weathering agencies, could be excluded from the mat, the life of the asphaltic oil and thereby the life of the mat, would be prolonged materially. It is our opinion at this time that oils of the SC type are best suited for dense mat construction. After a mat containing SC oil has been down a sufficient length of time to allow proper curing it is believed that sealing with RC cutback material will contribute greatly to the life of the mat This sealing may not be done in some cases until one year after the mat is laid. It is believed the good derived from shouldering up level with the mat is more than offset by the harm done by not allowing the free escape of water from the edge of the mat, which will result in edge failure.

Therefore, no shouldering up should be done, but a mat should be constructed with a feather edge and the cost of the shouldering should be put into additional width of the mat.

CONSTRUCTION

During construction it is very essential to have on the job a soils engineer with proper soils aquipment, consisting of Proctor Compaction Cylinders and penetration needle, density determination apparatus, stoves, sieves, and other general equipment as the conditions for the individual project demand.

The use of SC oil requires much closer attention on the part of the engineer in charge than does MC or RC material. A proper amount of SC oil is confined to much narrower limits than either the MC or RC oils. If too much oil is used bleeding will be the result in hot weather, and if an insufficient amount of oil is used it will result in raveling and premature disintegration. For this reason SC road oil should never be used when the temperature is below 65° Fahrenheit. If enough oil is added at low temperature to make the mat look right it results in bleeding during warm weather.

It is to be regretted that to date no satisfactory standard method has been devised to determine the proper amount of oil to be added to the aggregate to produce a satisfactory mat.

Stage construction of bituminous surfaces is not recommended for a number of reasons. (1) Stage construction exposes more of the mat to weathering and thereby shortens its life. (2) It is not always possible to build the second stage at the proper time, and unless it is, the first stage is lost entirely. Few highway departments can plan ahead and follow a definite schedule due to uncertainty of funds or changes in personnel and policies. (3) A job built complete at one time costs less than one built by stages due to contractors' moving and other additional items.

CONCLUSION

From the above it would appear that some subgrades may need treatment while others do not, depending on a number of factors. The use of wide right-of-way permitting the use of 6:1 shoulder slopes or berms is highly desirable for protecting the subgrade from moisture and for safety purposes.

The most densely graded aggregates appear to be the best to use and the oil giving the best results at this time appears to be SC oil.

Shouldering up along mats is not advisable as it appears to be part of the cause of edge failure.

SECTION IV

Maintenance of Bituminous Surfaces

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Review of the Maintenance of Bituminous Surfaces

By

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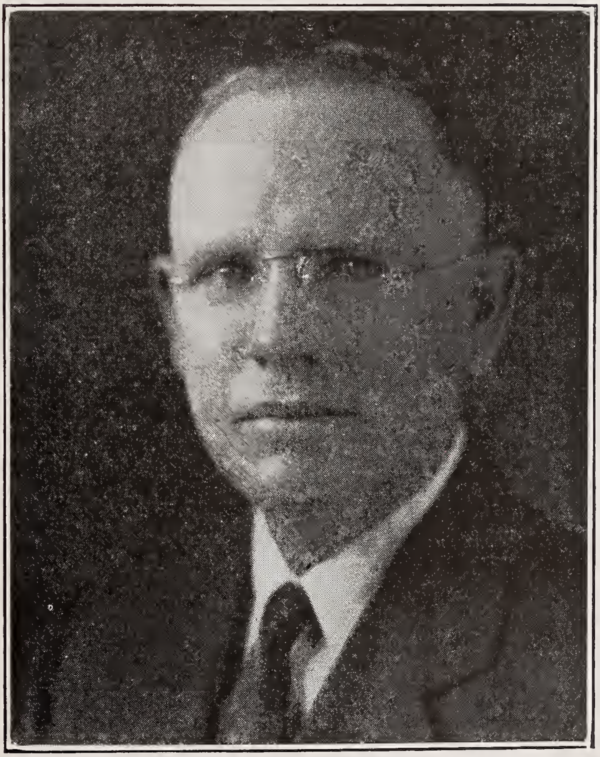

I know that many of you are in no mood to be trifled with or burdened with a long dissertation this morning and I assure you that my remarks will be brief for two reasons:

1st. In the press of official duties that had to be met and private obligations that I could not meet I didn't have the time to devote to the subject and with the committee which it merits.

2nd. I didn't have a clear picture of the differing practices over the country that is absolutely essential to a complete discussion of all the phases of maintenance and could not personally contact the committee in advance to get it. However, the committee has met several times here at the convention and we have gone over those phases of maintenance which are peculiar to bituminous surfaces and I feel that with their assistance we can at least provoke discussion from the platform and the floor that will be informative and lengthy enough to absorb all our allotted time.

If not, there are so many questions and topics that were not reached in yesterday's meeting that I am sure there is ample time for discussion this morning.

I don't want to step on any body's toes and if I should, I am sure you will forgive me in advance, when I tell you that I was a member of the discredited tribe of bridge engineers for many years, part of the time with the Bureau and during which time I went around trying to tear down all the Federal Aid bridges with an eight ounce hammer where the Contractor left any honeycomb, and got my first Indian name ''Tommy Hawk'' in Mississippi. Instead of a leather diploma from Sears Roebuck like I got last night, they gave me a rubber hammered tomahawk.

The Committee has intimated that I had better use it this morning. They may take exception to some of my expressions and I am sure some of you will at recess. Please hand me any questions you would like to have brought before the Conference.

Carefully and excellently prepared papers indicate the attention now being paid the engineering control and organization of maintenance, and it is regrettable that these papers were not available for general distribution prior to the meeting.

The importance and true function of maintenance has been neglected in the past and the construction or the process of building the highway and its surface has been over-emphasized. The natural tendency of construction engineers and builders is to build, or hope they are building, forever, and to feel that their work and responsibility ends with the final construction inspection when they turn it over to the operators, the maintenance organization.

All to often, in effect at least, the maintenance and construction organizations in otherwise well organized Highway Departments have been entirely separated. In some cases little or no real engineering control was exerted over the maintenance activities which were in the hands of practical men or politicians. However, all highway engineers are at last coming to realize that while it may be possible to sometime reach millennium when all the roads that the people need or want will have been built and paved, there is no question but that highways will have to be maintained forever.

With the unlimited public demand for paved highways, the increasing burden of maintenance, the cognizance that the public road purse is limited and that no road will endure or serve indefinitely, there is more unity of purpose and concerted effort in the Highway Departments of the nation to analyze and reduce the costs of maintenance. Engineers are giving more attention to design details and construction procedures that will avoid and minimize future maintenance. That is, more engineering skill is being exercised to eliminate the necessity for repair work.

The closer the coordination between design, construction and maintenance, the more will be obtained from the highway dollar. In the past the expenditures incurred in attempting to provide adequate highway service over roads improperly located, incorrectly designed, or whose surfaces were built of defective material or placed on faulty foundations have often made up a greater percentage of the annual maintenance cost than the expenditures chargeable strictly to maintenance of the surface itself.

When a road is so located that damaging earth or water movements are avoided, so graded and drained with proper slopes, ditches, structures and appurtenances that damaging erosion is prevented, with subgrade and base foundation course so constructed that it will remain stable under the traffic loads during extreme local climatic conditions, and a well-designed bituminous surface composed of good materials properly placed thereon, little or no surface maintenance should ever be required, except seals or retreads at increasingly longer intervals to replace the ordinary wear and correct the surface deformations that come with time.

Much has been said of the economics of surface types but except in rare instances such statements have been made without definite information as to the actual service life of the type involved, the true maintenance costs chargeable directly to the type, the liklihood of the obsolescence of the type or the adaptability of the type to stage improvement or rehabilitation. This is true because sufficient, accurate, dependable maintenance cost data has not yet become available and the real economic value of types is still a matter of opinion even though the opinion be formed on the best of judgment. Only in isolated cases and under few governing conditions, have there been real opportunities to determine the service life of the modern bituminous low-cost surface types. You can never determine the real merit of any surface type or even of any grade of bitumen or character of aggregate, so long as the maintenance expense, hazard and inconvenience to traffic is due to a foundation that would not hold up any type for its true service life.

Through the medium of traffic surveys already completed, or in progress in cooperation with the Bureau of Public Roads, the Highway Departments are at last approaching the point where present traffic is, or will be known, and future traffic will be predictable within a reasonable degree of accuracy. We do not know that many thin mats and surface treatments on substantial foundations are successfully carrying large volumes of traffic at almost unbelievable low cost. It is high time the general public and many engineers were disabused of the idea that it requires a high cost, high type surface to carry any appreciable volume of traffic.

However, a number of well-designed low-cost surface types have been developed past the experimental stage and sufficient mileage of these types has been built and in service long enough to determine the respective service life of each and their economic value and an impartial study of, and determination of. the true maintenance charge on a selected substantial mileage of these over the country would prove of immense and immediate benefit to everyone concerned in highway transportation.

When properly designed and constructed of good materials, on a stable foundation, a number of the proven types are economical in first cost and in obsolescence and many engineers now feel that they can be maintained and improved at far less total annual cost than any kind of surface yet developed. and much cheaper than the so-called high-type pavements.

It is the duty of highway administrators to so mold their cost accounting systems that the cost data present the fundamental facts on the highway investment for their own and the taxpayers' guidance if they are to fulfill their duty as the builders and operators of the world's greatest public utility. It is indeed unfortunate that political conditions and material propaganda have many times caused maintenance cost data to be concealed and distorted. Only within the last few years has there been any uniformity in the methods of accounting but as yet we have accumulated very little comparable data. It is very unfortunate that we do not have accurate maintenance cost data on low cost bituminous surface types. While each state has more or less accurate records of what that State has spent on its mileage of bituminous roads, many items of expense that enter the cost of maintenance are entirely independent of and bear no relation whatever to the type of surface and with the popular demands for better and additional traffic service, more are continually being added. All these independent cost items must be separated from those chargeable to surface alone before a true picture will be obtained from which reliable conclusions can be drawn.

Only within the last few years have the real fundamentals of low cost road design been recognized. Thousands of miles have been laid with varying degrees of success on the natural soil or on existing or non-existent temporary surfaces. Much or all of the expense of their resuscitation, as well as, their true maintenance cost has usually been charged to maintenance. Such expense is not chargeable to maintenance of the type. In fact it is not maintenance expense at all, unless the Highway Department is knowingly and openly proceeding with that fact in mind and is willing to and feels justified in tearing up and reworking a large percentage of the road mileage each year because it can't do otherwise. However, when such are carried along regardless of economy waiting for funds to reconstruct, there should be no attempt to fool ourselves or others.

There is immediate need of and close adherence to uniform accounting methods that will develop the annual charge for strictly maintenance purposes per mile of bituminous surface of each of the principal types over the range of traffic volumes and service to which each is best adapted. In this maintenance accounting, it must be borne in mind that no matter how well the system is designed it will not truly represent the expense strictly chargeable to maintaining the surface unless those field employees who obtain and furnish the information to the accountants are carefully instructed as to just what items of expense should be included, and competent supervision exercised to insure that the instructions are followed, because the separation between the items of expense is often difficult or indistinct.

It is vital to know what this maintenance cost is for each type and which of the available proven types is the most economical for a given locality.

The need for roads is so great and the taxpayer's ability to pay so limited that it behooves the highway administrator to obtain the utmost in traffic service from every highway dollar. Every penny spent on a highway surface over and above that required to provide and maintain 100 percent highway service is money wasted.

Maintenance problems increase with water and this is especially true where it has not been taken care of properly by the designers or the builders. The effects of climatic variations such as alternate freezing and thawing, and prolonged dry or wet weather must be met, but they have and can be met in the selection design and construction of the foundation course and surface. It is high time that engineers stopped believing or trying to make their public believe the "spring break-up" is inevitable. Such belief might have been excusable a few years ago, but it is a confession of ignorance now. "Spring break-ups" are only inevitable on those sections improperly constructed or built for temporary or make-shift service without expectation that they would withstand them. Maintenance budgets have continued to bear the burden of keeping such make-shift construction in service much longer than justifiable, by nursing purely temporary traffic alleviation long past its intended or economic traffic service life. When this is done it should be done with full knowledge of the facts and a real defense for doing it.

When the expense of maintaining a surface becomes greater than the cost of amortizing a reconstruction that will provide 100 percent traffic service, the surface and foundation course should be corrected or rebuilt from the bottom up instead of annually or oftener, spreading money over the top in futile efforts to "cover up," temporize or postpone the day of reckoning. In the Eastern section of the United States the practice is to cover up instead of tear up. There has been too much ill-advised expenditures in haphazard repair work and futile attempts to strengthen surfaces to carry the loads laid on weak, unstable foundations, when it should have been clearly evident that reconstruction was inevitable, and economical unless it is impossible to secure the funds required to do the proper job at once or in stages.

Fortunately the tendency to try to cover up recognized failures where possible to do otherwise is decreasing. Many engineers are now reconstructing their failures and preventing further loss and waste as soon as practicable, but a few still persist in trying to conceal them every spring at the expense of the maintenance budget.

With the increased knowledge of the chemistry and physics of soils there has come realization that the natural laws and forces involved must be met to produce stable and durable foundations and surfaces.

More and closer attention is being paid to building of stable subgrades and stable base or foundation courses with the result that the necessity of repairs, reworking, and reconstruction of bituminous surfaces due to faulty subgrade or unstable foundation base course or lack of foundation is steadily decreasing.

There has been noticeable increase in the quality of bituminous surface types placed within the last two years due to more careful selection of aggregates and bitumen, better design of mats and mixes, and improved and more seasonable construction procedures, and as a result there has already been a corresponding decrease in early failures in the bituminous surface itself. At 70 miles an hour the reason for many surface failures can be seen by looking at the soil in the cuts and ditches.

In the past and as yet in all too many instances, the field maintenance forces proceed to patch, repair, tear up, remix, reconstruct and replace without consulting the materials or testing engineer or analyzing, determining and correcting the foundation defects or only partially so. The result is all too often repeated or at the best delayed failures.

There is increased recognition of the necessity of analyzing and classifying failures in bituminous surfaces before attempting extensive repairs in order to reach an intelligent decision as to whether repair, reworking or reconstruction is the economical procedure and as to the proper methods to be used in the procedure adopted. Many states, including my own, have not yet completely mastered the art and science of the successful patching of minor foundation failures. There's much to this small item or rather to prevent it from being a repeated large item and it is apparent on the surface if you look for it.

The necessary maintenance of bituminous surfaces cannot be economically and efficiently performed unless the work is planned in advance and performed in the proper season. This is impossible unless funds for maintenance are available, and are budgeted to carry out the work, when and during the season, when it should be done. Of course, emergency repairs must be given attention and handled immediately at least in a temporary way, regardless of season, conditions, or funds. However, real economy can only be attained through careful, definite, planned and budgeted maintenance in which provision is made for periodic seals and retreatments at intervals as they become necessary. Intelligently planned, retreatments or retreading can easily be developed into stage construction of the bituminous surface that will build the type up to and with the traffic, even increasing the lane or pavement width as may be necessary. Many engineers are now designing and planning successive retreatments to increase the thickness and improve the riding qualities of the original surface, thereby giving the travelling public a new, improved surface with each retreatment.

The difference between resurfacing expense and maintenance cost is not clearly distinct. Improvement beyond maintenance to the condition built, is certainly a consistent construction charge.

There is a definite trend toward the use of less bitumen and better mixing and toward a coarser, more flexible texture for leveling courses on old pavements and for retread work.

There is decrease in the use of seal coats of bitumen without aggregate or cover material in the East but their use continues in the West due to differences in type and climatic conditions. In the East seal coats are now being used that strengthen and thicken the mat and provide non-skid texture. There has been much effective treating of slick, slippery surfaces in the interest of safety, and many sections have clearly demonstrated that a bituminous surface can be built close and tight enough to resist the action of high speed, low pressure tires, yet open enough to provide a safe, non-skid surface, and so maintained.

The trend is increasingly toward the use of pre-mixed material for patching, sealing and retreading. Where plants are used for pre-mixing, many are now being equipped with driers especially where moisture in the aggregate has proved troublesome. Many are adapting their seal and retread specifications and practice to permit the utilization of aggregates locally available. It is apparent that the future will require more and more retreading operations. The public continually demands a safer and more comfortable riding surface and it is only a question of time until all or nearly all the so-called high type pavements must be retreaded to provide a smooth non-skid surface—in effect, a new pavement.

Better organization and better methods have simplified the detour problem and maintenance is being performed with less and less interference with traffic. Even extensive reconstruction operations are now carried out without resorting to other than simple detours alongside or around very short sections.

The base or foundation courses are being extended well beyond the edge of the intended bituminous surfacing and the shoulders kept below and sloping away from the edge of the bituminous surfacing. Many otherwise successful bituminous surfaces have deteriorated to the point requiring reconstruction of base and surface due to ponding of water at the edges with consequent softening and troughing of base and surface under the pounding of traffic, due to originally constructing the shoulders flat and level with the surface, or to their gradual building up above the surface through soil accumulation or grass roots. Especially has this been true in regions of heavy rainfall and particularly on center stripped roads.

The majority of maintenance engineers have at last learned that capillary water must be controlled to prevent certain destruction of the surfacing and that it cannot be removed by ordinary drainage methods.

While there appears room for improvement in the practice of making minor repairs the practice of maintenance organizations in general is much more systematic and greatly improved. Remixing, reworking and stabilizing is being carried out in a much more intelligent manner and more lasting results are being obtained.

There has been a definite trend toward the replacement of gasoline driven equipment to Diesel equipment. Patrol graders are more and more used instead of tractor drawn graders and the horse drawn grader is almost obsolete.

I think that previous papers and discussions have definitely brought out the trend toward the use of SC bitumen instead of MC in maintenance work.

Mr. Roherty, one of the committee members has offered a suggestion which the committee feels might well be followed on construction: namely, that a liberal sample of the bitumens used on any maintenance be kept for future reference.

The need of this country is millions of miles of all weather road within the reach of the public purse, low cost road, not only low in first cost but low in maintenance cost. It's up to the highway engineering profession to discover and develop types that will fulfill this need. In fact it is our duty. I believe that such a bituminous road can be developed, certainly we have progressed farther to this end in the last few years than in all the previous age of road building. With a durable cementing medium, I believe we can practically eliminate all surface maintenance costs except the ordinary wear and tear of traffic.

We are spending too much on surface maintenance. Unless we reduce this visible expense the public will demand that we revert to the higher types. We must acknowledge our mistakes and keep an open mind. The trend of this meeting shows that more and more engineers are realizing that there are yet many unsolved problems and that none of us know all about any one phase of road building.

We must get away from the idea that a low cost road means a continual drain on the maintenance budget. Instead of the sign "Road Repairs Just Ahead" our slogan should be "Road Repairs Are Being Left Behind—Betterment Operations Ahead."

Conference on Maintenance of Bituminous Surfaces

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Mr. Houk: I think we will now proceed with the discussion for a few minutes before the recess. I would like to call on Mr. Nuss.

Mr. Nuss:
Kansas

Yesterday when the committee was in meeting we discussed briefly the relationship that should exist between the design department and the maintenance department as it affects future maintenance. I think everyone interested in maintenance realizes that design is the thing that affects maintenance to a great extent. By that I mean the little details of design that look good on paper but do not always work out well on maintenance. With that in mind I think most states could well afford to bring about a closer cooperation between the design and maintenance departments. In Kansas we are going to, in the future, have a maintenance engineer along in the field checking practices and I think it is going to result in a lot of little changes that will affect the cost of maintenance. In the past our method of building shoulders has given us considerable trouble. We do not have available local material such as gravel or other material. Even rock to a certain extent is scarce in Kansas. So we have had to shoulder in the past with soil and most of it in the eastern part is clay. Clay has a tendency to hold moisture, and I think this is responsible for a good share of our trouble in edge failures.

The maintenance department has continuously more or less harped on that thing, but after the road is built it is too late. All you can do is go out and cut the shoulder off, but the money spent for that shoulder is already gone. What we are trying to do now is bring about a closer relationship between the maintenance department and the design department and to do this will cut our maintenance cost and not increase our construction cost. I would like to hear from some of the states in that regard, if you have solved that problem in a better way or what you are doing. Does anyone have any problems along that line or have had and have solved them?

Mr. Shumate: Colorado

In Colorado we have recently developed a practice that seems to help considerably with failures in the edge of our oil mat, whereby in the mat or base the amount of loose material is clipped off the base and the base mat is laid directly on top. The edges are left as nearly vertical as possible, and we have given our shoulders a slope of approximately one inch per foot of width out to the edge of the shoulder.

In a great many cases we have found that our shoulder material which was failing in taking the treatment of the base did not have sufficient binder in it to compact sufficiently, and we have gone in and added sufficient mineral binder to compact sufficiently. We have found in doing this that we get a rapid run-off in the edge of our oil, and it has done a lot to prevent breaking at the edge. In some of our high mountain places we have a rather severe snow condition, and especially in the period of the year when thawing starts, we have been unable to find any satisfactory condition or solution to correct that condition. I thought perhaps some of the men who have similar conditions on bituminous roads could give us some information on how they remedy the external water circulating in the edge of the oil mat.

Mr. Houk: Has anyone else any suggestions along the line of closer cooperation between the construction, design, and maintenance departments?

Prof. Lang: Minnesota

Mr. Chairman, I don't know if it's exactly maintenance, but we have a soil engineer who works with the design department, a soil engineer who has had considerable experience in the field, and the design department as far as possible tries to establish the correct thickness of the bases to avoid these weak spots of which you speak.

Mr. Houk: I find some of the states are investigating the soil conditions under their failures and that others just authorize the maintenance forces to go out and do what they think is necessary or that is what is actually done. The failure often repeats itself; in fact, more often than not. Anyone anything to say along that line?

Mr. Perry:
Iowa

I see no reason whatever for not utilizing all the talent that you have in your organization. I refer to your design department, to your research department, and the results that the construction engineers and the maintenance engineers can secure by that cooperation. We are fortunate in Iowa that the differences you mention here appear foreign to me. When we have a problem we have no hesitancy in taking the problem directly to the design department or the research department and when necessary take the men from those departments to the field and seek a solution. It seems to me this is the only practical way to do.

Just a word regarding shoulder trouble due to moisture getting under the mat. We oil the shoulders in order to seal between the mat and the shoulder. On some of our earlier stabilized bases, the shoulders were not sealed and the moisture which ran off from the mat seeped under the edges of the stabilized base. Now we treat the shoulder with oil using practically no cover material. About three treatments seem to give us a well water-proofed shoulder.

Mr. Houk: Mr. Nuss would like Mr. Perry to state what grade of material was used on that shoulder.

Mr. Perry:
Iowa

We have used SC's and also the MC's. The first treatment is the prime that is used in the regular construction, an MC-1 or possibly an MC-2. Follow up the next year with an application of one-quarter to three-tenths gallon to the square yard on a four or five foot width, depending on the width of shoulder. At the time of each treatment the shoulder is swept clean, the bitumen applied and then this material brushed back over in order to form as much of a mat as possible.

Mr. Houk:

Has anyone else an extensive program of shoulder treatment?

Mr. Shumate:
Colorado

I would like to ask Mr. Perry one question. Does this shoulder present a black appearance, the same as the bituminous mat?

Mr. Perry:
Iowa

The first treatment is black. Subsequent treatments are lighter in color due to the sweepings which are spread over the bitumen.

Mr. Shumate:
Colorado

We tried draining the shoulder on one experimental section, and we had to go back in and take the mat off the shoulder on account of the safety factor that was involved. The people that traveled it put up quite a protest, and it really was hard to see, as there was no defining boundary to the edge of the road, and we had to remove the mat from the shoulder.

Prof. Lang:
Minnesota

How wide was the road? Did it have a center line mark? I think that would help.

Mr. Shumate:
Colorado

Twenty-two feet. It had no center marker.

Mr. Houk:

In the West I know it is the practice to use bituminous material on the shoulder without cover. In the East they usually use chips on the shoulder.

Mr. Russell:
Wyoming

We have one short experimental stretch that might be of some interest. I can't give you all the details because I didn't go into them too thoroughly. We took three quarter-mile sections and tried a different method on each. The project originally called for a 24′ mat with 6′ shoulders of gravel on each side.

The first experimental section was constructed with the mat extending from shoulder to shoulder. That, of course, introduces somewhat of a danger factor, since the black surface absorbs light, making it difficult to see the edge. The experiment thus far appears to be a success, and we have as yet received no criticism. Some means of clearly defining the edge would be advantageous.

On the next section, a 24′ mat was constructed and the 6′ gravel shoulders were stabilized with calcium chloride. No appreciable improvement has been noted over our customary method of binder stabilization by using the calcium chloride. This may be due to the low humidity that prevails.

The third of the sections was constructed with the 24′ mat and cement stabilized shoulders. The windrow of shoulder gravel was placed on the finished oiled mat and mixed with cement and water to make a low cement-content concrete. On one side of the section 4% of cement was used in the mix, and on the opposite side 6% was used. No appreciable difference in results is noticeable. Mixing was accomplished by using a blade grader. After mixing, the concrete was bladed into place on the shoulder and compacted by means of a truck.

This method of stabilizing shoulder gravel appears to have some merit, provided suitable equipment for doing the mixing could be devised. A machine of somewhat the same type as the Woods traveling mixer, commonly used for oil mixing, could perhaps be adapted to this work. After some six months' service, these shoulders have shown no signs of cracking or wear. The color contrast between the oil mat and the stabilized shoulder also adds to the safety of night driving.

Another manner in which we have attempted to carry surface water to the slopes and away from the mat edge is by giving the shoulder section a double prime. Our practice now is to prime the base course from shoulder to shoulder with about three-tenths gallon per square yard. After the mat has been laid and rolled, a second application of RC-2 is placed on the full shoulder and extended up over the edge of the mat for a few inches. The shoulder gravel is placed above this second prime. In this manner, a waterproof membrane extends from the mat to the slope which insures the surface water being carried away from the mat.

Mr. Houk: Mr. Jones, I believe you have had some experience with treated shoulder mats and also with MC sealing.

Mr. Jones:
Oklahoma

This year we have experienced a few new ideas on the shoulder treatment. It is not so general yet, but we have formulated some ideas that I think will be good. Our road bed, normally 36 feet, is built to correct sections from shoulder to shoulder; the material is added on the shoulder, blended if necessary to give the proper grading and metered to give the exact volume per unit of length; then the road bed is primed 22 feet wide, we are laying a 20-foot mat, the mat is built and the shoulder is oiled without shouldering up.

Keep in mind now, we want this mat to be above the base line. That will leave the shoulder, say two to two and one-half inches lower than the top of the mat. We then go over this shoulder with the MC-1, our prime oil, using one spray which will just barely touch and overlap the edge of the mat thereby creating a slight richness at this point. The traffic in time will beat down that verticle edge until it will be more nearly a 45° angle slope, and in that way cars have no difficulty in getting off the mat or back on. The shoulder may even be shot again with oil, using the same grade of oil that we used in the mat. We never place chips on the shoulder. However, there are always a few pebbles and a small amount of chips on the edge of the shoulder that get on the mat, likely brushed over from the shoulder. It doesn't hurt anything. It changes the color slightly, but doesn't interfere with the water, and by having the shoulder just a little lower than the mat there is a distinction in that the line can be seen, and even at night if you cannot see it, the minute you get over the edge you can feel it although it does not represent much of a hazard. Understand, please, we have not done much of this, but it is one of the new thoughts we have had this summer: we have been doing some of it and so far like it very much.

Mr. Houk: Has anyone else anything to offer on maintenance of shoulders?

Mr. Harsch:
California

I don't know how much you gentlemen have observed in the maintenance of shoulders with either surface treatment or mixed mats, but it has been my observation in California, where it is almost standard practice to oil three to six feet on either side of the pavement, that unless there is sufficient base under that oiled treatment, your maintenance is going to increase considerably.

Mr. Houk: That was exactly the question I was going to ask. Of course, the base course material, being full width of shoulders if I understand correctly, wouldn't require any additional material. If the shoulders are of base course material, they will support the shoulder treatment. Otherwise, base material must be placed thereon or treatment other than oiling given to maintain the shoulders, and that is the practice in South Carolina where they have just started a rather extensive program of shoulder treatment.

Mr. Hveem:
California

I might add that in California at the present time soils proposed for shoulder construction are tested to see if they are suitable for oil treatment. If they are not, attempts are made to find selected material or other aggregate that would satisfactorily take oil treatment. This material is placed on the shoulder for that purpose. Oiling shoulders beyond the edge of the pavement is standard practice and has been for a number of years. We have placed oil shoulders up to 16′ in width.

Mr. Gray:
New York

That point that was brought up by Mr. Harsch is extremely well taken, and where the shoulder is oiled a provision should be made at the same time for taking care of a certain amount of the settlement that is bound to occur, particularly if big trucks get over the edge. Through the New England states it is the general practice to oil the shoulder whether adjacent to a mat or a high type pavement. The procedure is to run the distributor along the edge of the pavement using a canvas shield, so as to confine the asphalt to the shoulder; then follow immediately behind with a small harrow or drag to mix the asphalt and aggregate. A penetration of approximately an inch or inch and one-half is obtained. Then let traffic over it and within a very few days a big truck will turn out and may cause a settlement of as much as three inches. If nothing is done about it, the depression will hold water and you have made a bad matter worse. So to take care of such contingencies a stock pile of pre-mixed material is made up, using the same kind of oil which was applied by the distributor, and the same kind of aggregate as in the shoulder. Every so often during the first season a maintenance man goes along and throws a shovelfull of mix into these different depressions until all the weak spots are stabilized and no more settlement occurs.

It sounds like a lot of work, but within a year or two completely stable shoulders four to six feet wide are secured. In the annual maintenence report for Rhode Island it was stated that the reduction in cost of cleaning drainage structures alone more than made up for the expenditure of keeping building the shoulders to a greater stability.

Mr. Black: Illinois
I wonder if anyone has given any consideration to the possibilities of using a narrow strip of membrane inserted under the edge of the mat so that it will extend out into the shoulder and under the mat a suitable distance, possibly a foot, carrying off the drainage in that way to the shoulder. The same way the flashing carries water off a roof.

Mr. Houk: That is an interesting suggestion. Has anyone else any thought along that line? Has anyone else anything to say on shoulder maintenance. Does anyone on the committee wish to add to this discussion?

Mr. Jones of Oklahoma, who is a member of the committee, thinks it is well to emphasize the fact that there is a distinct trend among many of the states to increase the engineering and field control of bituminous work in regard to maintenance construction. I understand Mr. Bishop of Oregon gets out an annual maintenance bulletin descriptive of the work done in Oregon. We would like to hear from him.

Mr. Bishop: Oregon
Why, the manual we get out in Salem, Oregon on the type of maintenance carried on in Oregon is quite different from other states due to the fact that there are no S or M oils used, all being bituminous macadam maintenance and the manual is more of an organization manual and equipment bulletin. I don't know as I have anything to add.

Mr. Houk: Mr. Jones, could you discuss your instructions?

Mr. Jones:
Oklahoma

There were several years in which Oklahoma did not make much progress in bituminous work. Beginning with the summer of '35 there was an increase in bituminous work, and at that time it became evident that our field men were lacking in knowledge, not only of the elementary purposes of oils, but details of manipulation and as how to secure the best results.

In January this year our bituminous engineer, Mr. Black, together with the maintenance department, prepared a rather voluminous bituminous manual that gave instructions in elementary form of the kind of oils and hard asphalts. Then he went into the details of manipulation; then into proper organization in the field; then into the various tests and the controls; and finally into the various reports that should be submitted through the field to the division office.

That manual became immediately very popular for the reason that many of the men in the field were bituminous-minded and seemed to be hungry for information. We placed those manuals in the field with the engineers, our superintendents and our foremen, and on down to the motor patrol operators. And we think that that has been a very good step taken. Oklahoma, through necessity, has to do much of its bituminous construction work through the maintenance department. Not a great deal of it is contracted and that causes the bituminous engineer to have to work very closely with the maintenance department because he has to use maintenance equipment and maintenance men in many cases.

From the various department heads in the central office all those functions are centralized; again in the division office under the division engineers; from there the split is again made to assistant division engineer of construc tion and assistant engineer in charge of maintenance. That causes again the construction department and maintenance department in the field to work very closely together. So with that arrangement of the organization, I think it is very good and makes it easy for general instructions in the bituminous manual and all other pertinent information that we are able to gather in the Oklahoma City office to reach the man far out in the field.

Mr. Houk: Thank you, Mr. Jones. Has anyone else anything to say in regard to their manual or any special or general instructions issued as to maintenance operations and procedure? While we are speaking of the corrections or reconstruction of bituminous roads, there seems to be some difference in the ideas conveyed by different terminology, such as "foundation," "stabilized base," and "base course." I would like Mr. Jordan of Alabama to explain just what we of the South mean when we speak of base course or foundation course.

Mr. Jordan:
Alabama

I must say that we have been somewhat confused by some of the terms used in this portion of the country in referring to stabilization. In Alabama we use the terms "subgrade" or "foundation," "subgrade treatment," "stabilization," and "base course." By subgrade we mean the roadbed on which the base course or pavement is to be placed. By subgrade treatment we mean such treatment of the subgrade as is necessary to prepare it to serve satisfactorily as a foundation for the base course. While this may include removal and replacement of small areas of bad soil, or the mixing of suitable materials with the subgrade soil, it generally consists of placing on top of any sections of the original subgrade that need treatment select soil of such quality and thickness as is deemed necessary to make a prepared subgrade capable of satisfactorily supporting the base course. This subgrade preparation work is planned by a soils engineer. Much of our recent base construction and bituminous surface treatment has been along State roads that have been under traffic for several years and on which the temporary surfacing had worn very thin and the surface out of shape. On these, the subgrade preparation work includes, in addition to the treatment of the grade for bearing power, such leveling and superelevation work as is needed, and which is accomplished partially by hard blading, but principally by adding, in the low places and on the outside of curves, a sufficient quantity of the same select material used to treat the grade for bearing power. This prepared subgrade is maintained to sections parallel to the finished surface until consolidated. What we call the base course is then placed on this prepared subgrade to a uniform minimum depth of six to eight inches and frequently to full width of grade, though select roadside material is commonly used for shoulders. The base course is usually of roadside materials such as sand clay, topsoil, sand clay gravel, chert, etc. Seldom are we able to build a satisfactory base without mixing two or more of these local materials. And, seldom are we unable to find, locally, materials that can be combined in such proportions as to make a suitable base, though weeks of investigation by soils engineers are sometimes necessary.

When we use the term stabilization it is in a very general sense. It may refer to the subgrade preparation work when materials are incorporated with the subgrade soil; or it may refer to the addition of aggregates to a sand clay base to increase bearing power; or it may refer to the addition of sand or other fine granular material to a base material to reduce the clay content of the soil binder. The term "stabilized base" is seldom used. The aim is to make all bases stable. The methods vary materially, depending on the nature of the materials being used.

A few years ago bituminous surface treatments were placed on several sections of roads in Alabama which had been maintained as gravel roads for several years, and on which it was thought that the sand and gravel had become sufficiently incorporated in the grade to stabilize it. Failures were extensive. Where there was sufficient sand in the gravel it did not work deep enough into the grade. When it worked down the gravel kept going down and the clay kept coming up.

Base courses were prepared on a few projects by mixing granular materials with the soil in the grade to sufficient depth to form what was considered a base. This was also a failure. Due to the wide variation in soils in the grade it was not practical to control properly the gradation and quality of the soil binder resulting from the operation.

The experience of the Alabama Highway Department in maintaining bituminous surfaces has convinced it that there is no economy in placing its bituminous surfaces on anything other than a well constructed base laid on a well prepared subgrade. The added first cost is more than saved during the first few years of maintenance, without including the value of having a road surface with such base and foundation under it that the surface can be safely built up in the future as traffic demands.

Mr. Houk: Mr. Jordan happens at present to be division engineer at Birmingham where we may have a hundred soils in one cut. I am sure there is no place in the country that I have seen, in Mexico or the United States, where there are any worse soils to deal with than that we have in that area insofar as securing a stable foundation for a bituminous course is concerned. In addition to varied soil we have also a heavy rainfall.

The question has been raised and I think it is a rather pertinent one at this time as to the advisability of center striping low cost bituminous surfaces, especially road mix and thin mat surfaces. Mr. Johnson of Missouri prepared a special paper on this for presentation, and I would like to ask him to present it at this time.

(Paper presented by J. A. Johnson. See Page 546.)

Mr. Houk: Anyone else anything to say on center striping? I notice that a number of states are using double striping. I have noticed also that some of the states in the snow country use yellow paint, as white is not effectvie.

Mr. Jones:
Oklahoma
Mr. Johnson, I would just like to ask, was this a lacquer paint?

Mr. Johnson:
Missouri
Yes, it was a lacquer paint.

Mr. Houk: Mr. Phillips, have you anything on center striping which you might add?

Mr. Phillips:
Wyoming
We have. Unfortunately, our last legislature made it mandatory upon us to center stripe our primary system. Up to that time we had center striped in a solid line five inches wide over vertical and horizontal curves only, due to narrow road bed widths. We are trying this year the same solid line on the vertical and horizontal curves and dot and dash system on the tangent. We are also doing some double line striping on the vertical and horizontal curves. It is apparent already it is costing us about twelve dollars a mile, but we are having some trouble trying to get truck drivers that can stay in the middle of the road, and I was

wondering if there is anyone that could tell me if there is a way of lining up a truck without depending upon the truck driver too much by the use of targets or otherwise.

I believe Mr. Houk remarked about our orange stripe. That is slightly embarrassing to me when I see all the stripes are white in Montana, with identical weather conditions. We do use that color, however, for what we think is greater visibility under snow conditions in the winter time. We have used several different kinds of lacquers and paint, and at the present time we are using a lacquer that was formulated by Mr. Russell. He could probably tell you something about that. I don't understand its makeup at all, but it is of the quick-drying variety.

Mr. Houk: Mr. Gould, could you tell us anything of the practice in Iowa? Does anyone have anything to tell us of the practice in Iowa?

Mr. Perry:
Iowa

We haven't used any striping on the bituminous roads in recent years. We are fussing around a little on a cheap spray paint that we could use to indicate the outside edge of the mat or stabilized base. We have eliminated the center stripe as it forces traffic to the outside, putting additional stress on the shoulders. You may not all agree with us on this. I have nothing to offer on the paint at this time except that it is a lime and cement proposition.

Mr. Houk: Has anyone tried glass beads?

Mr. Zass:
Arkansas

Mr. Chairman, I would like to hear further expression from Mr. Perry as to the success they feel they are obtaining in eliminating the center stripe and in painting the outside edges to control traffic.

Mr. Perry:
Iowa

I don't know that I can point to definite results. On the other hand, we think that our roads are standing up better by the elimination of the center stripe, but the demand from the traveling public has caused us to seek a solution of the marking problem and we propose to mark the outside edges. We hope that we can work out a cheap center line marking that will be effective.

Mr. Houk: Has anyone else anything to offer on the center line striping and its advisability? What are the arguments pro and con?

Prof. Lang:
Minnesota
It is difficult for me to see how marking the edges is going to keep traffic in the center unless they have a narrow road. I would think the tendency would be for the automobile driver to drive close to the mark they have on the edge. I would like to get Mr. Perry on his feet again over this. I understand you are working with a cold water paint.

Mr. Perry:
Iowa
That is correct. We hope to develop a cold water paint for this purpose.

Mr. Zass:
Arkansas
I had thought something of that, and while we haven't tried it, we thought we might try it out. We haven't convinced them yet that we should put it on our outer edges. We probably won't have anywhere near the jar on the stripe that you would on your center stripe, and I was very interested in finding out if anyone has tried anything in the way of cold water paint.

Mr. Houk: What is California's experience in striping?

Mr. Hveem:
California
I am not thoroughly familiar with the details of traffic striping in California. We use lacquer paint from a formula developed by Dr. Lichthardt, Chief Chemist, and practically all roads in the highway system have a complete continuous center stripe. On all vertical or horizontal curves where sight distance is limited, California uses double line center striping with warning signs prohibiting passing over the double line. In the San Joaquin Valley area,

there are occasional heavy fogs, and a few years ago some of the two-lane pavement was striped both in the center and near the edges. White paint was used on the center stripe and orange paint near the edge. This edge striping appeared to be very effective in fog driving, but has since been discontinued. I am not in a position to say just why, probably due to the expense.

Mr. Houk: Now as to striping in the center lanes, may I ask if any states use aggregate in the stripes besides Mississippi? Mr. Draper, are you continuing that on bituminous roads?

Mr. Draper: Mississippi
We have not used it very much on what might be called low cost pavement. We prefer the white paint. But the aggregate chip stripe is continued on high type pavements.

Mr. Houk: Is there any question that anyone on the floor would like to have brought up for discussion? I would be glad to have suggestions. Have any of you any particular topic? If not, Mr. Nuss would like to hear a short discussion of the type of materials used for patching and whether better results are being obtained with cold mixes or hot mixes in patching.

Mr. Hveem: California
Probably this has to do with traffic striping. California has adopted the practice of placing small reflector buttons on all curves on heavy traffic highways. These buttons show up very well and provide a series of bright spots on the center line. They have a high-lighting effect on the curves and make driving safer for people not familiar with the road. They are particularly helpful in the fog.

Mr. Houk: May I ask if Minnesota is still using these reflectors?

Prof. Lang: Minnesota
More than I have seen anywhere else, and they are still using them.

Mr. Nuss:
Kansas

Mr. Chairman, I would like to ask both Mr. Hveem and Mr. Lang what type of reflector buttons they are using. On those we have used in Kansas we apparently can't keep them clean so they will keep on reflecting. After traffic has gone over them for awhile and it rains on them and dust collects on them, they become of no value. I wondered if you are using a type perhaps different than we are.

Prof. Lang:
Minnesota

I really don't know. They have two or three types. They seem to be effective for quite a long period of time, but there is considerable replacement, especially in the spring of the year. As to whether or not they are cleaned, I haven't any evidence. I couldn't say positively, but I don't think so.

Mr. Houk:

Are any other states using reflectors?

Mr. Hveem:
California

Reflector buttons are installed and handled by our maintenance department. I have not had occasion to inquire as to the particular types they are using. In the past years they have tried a number of different designs. We use a photo-electric cell apparatus in the laboratory for measuring reflective properties of the buttons. All reflector buttons used are tested and must pass certain requirements. The type most frequently seen is the simple metal casting, a rather stream-lined affair. I have heard no adverse comments.

Mr. Nuss:
Kansas

From your description it seems they are very much like the type we are using, but in going through Kansas we find if they have been down six months to a year all you can tell is another bump in the road.

Mr. Draper:
Mississippi

Mr. Chairman, maybe I can give you an idea that we haven't tried ourselves, but recently I noticed where in the city of Jackson there were cracks in a concrete street that had been over-poured with about 120 penetration asphalt. There was a Coca-Cola stand on the corner and some boys established this as their headquarters and amused themselves by placing Coca-Cola bottle tops on the asphalt in these cracks. After about six months, now, they are the most effective things I have seen—and they are certainly economical!

Mr. Houk: Mr. Perry, I believe you have something to offer.

Mr. Perry:
Iowa
On these reflector buttons dusting over and eliminating any visibility, I think that is true. We have what we call our window-washing crew and they have to go around and clean them off every so often. It just has to be done as far as we know.

Mr. Hveem:
California
I might add that if anyone is interested, I will be glad to get that information and send it to you, or if you wish you can write in.

Mr. Vail:
Colorado
Mr. Chairman, I am interested in putting on chips. There has been a contractor in our state studying over using light chips in a wide spreader box. We, however, felt that we were not getting the full benefit of all the stickiness of the oil due to the dust film and while there is a centrifugal machine that does send the chips out first, the spreading is irregular. He has the spreader box attached to a small shaker screen and dirt and dust drops down, the intermediate size next, and then the bigger ones last.

The spreader has power of its own and moves ahead and in that way he gets the big stones down first, the intermediate next and dust on top. It gives a smooth job, and doesn't make a film to keep the chips from sticking. I think he is going to have it patented.

Prof. Lang:
Minnesota
What is the size of the larger stones? About one-half inch?

Mr. Vail:
Colorado
About three-eighths, as nearly one size as possible.

Mr. Houk: As I go about the country, the successful patch is the exception. I think one of the unsolved problems of maintenance is the successful patching of bituminous surfaces. I would like to hear some discussion of successful methods of patching or methods used in which the majority of the patches are successful. Mr. Nuss has been asking about the material which you use. Do you use matrix or hot mix or cold mix or penetration, or what do you use?

Mr. Draper: Mississippi

Mr. Chairman, as I see it, we needn't feel ashamed if we haven't been able to make our patches last very long. You can't make an old suit or an old broom of old materials and patches and make it last very long.

Mr. Hveem: California

We have patches on California roads that have held for some considerable time. The present trend in California is almost entirely to premixed patching material so far as it can be used. There has been a great deal of discussion in different districts. We have differences of opinion as to what constitutes good patching material. The Laboratory has made some studies in order to find out just what is necessary to make a good bituminous mixture for patching, and we have found this—that the type that may be used for the original pavement construction may not be satisfactory for patching material. It is not yet entirely clear just what factors must be kept just so in order to make good patches. We have examined samples of various mixtures, and it appears that uniformly graded aggregates without any cluster of one size are more essential to patching than in new construction. The binding medium most widely used is probably SC-4 road oil, although personally I favor the ROMC cutbacks. One district has used MC-2 cutback with good results and of course the difference between MC-2 and ROMC is not very great and it is probably only a matter of opinion as to which is most satisfactory. Either SC-4 or medium curing cutback mixtures can be kept in stockpiles for long periods. Some caution should be exercised if produced in commercial plants to see that the material is not overheated. There have been several cases where the solvent has been driven out due to high mixing temperatures, and the mixture had to be blasted out of the stockpile after a month or so. Mixtures produced by the maintenance forces using cold aggregates have often been more satisfactory than plant mixtures due to longer life and better workability.

Mr. Amort: Oregon — I don't like to hear someone say that a successful patch has not been developed. Under Mr. Bishop and Mr. Smith very successful patches are now being made by the use of portable asphalt plants. These plants have been used for a number of years, and during the summer season are sent all over the state. They are patching bituminous macadams, old asphaltic concrete pavements, and I want to say they are the finest patches I have seen anywhere in the country. Of course, temporary patching is still being done by the penetration method by the ordinary maintenance crews, but under Mr. Bishop's supervision he has a corps of trained men who are able to feather out a patch that is about as pretty as any you have ever seen. And I want anyone who goes through Oregon to take a look at some of the patches.

Mr. Nuss: Kansas — I would like to ask you about this equipment. Is that just a pug-mill plant for mixes?

Mr. Amort: Oregon — The plants were designed by the Oregon Maintenance and Equipment Departments, consisting of two drums of the concrete type, remodelled. They have live trunnions, and the aggregate is heated by torch methods. Drying is done in one drum while mixing is done in the other. These plants are able to put out between 100 and 150 tons of material a day, and

I am told by Mr. Bishop that the cost of producing this mixture by this method has been reduced from $14 to $6.10 per ton.

Mr. Nuss: Kansas — What gradation is that material? Is it densely graded aggregate?

Mr. Amort: Oregon — Densely graded aggregate. In some cases they are putting on patches of open graded types. They are doing some experimentation along that line. They are simulating the open amesite mixtures by using RC-4 cutback with very good success, in taking out depressions and putting it in resurface sections to see what the results would be as to permanence and non-skid feature.

Mr. Nuss: Kansas — What type of materials are you using in dense mixes?

Mr. Amort: Oregon — I am not quite familiar with it. I cannot tell you the exact gradation.

Mr. Jones: Oklahoma — I would like to tell you just a little of the method we use. At the time of construction of our low cost bituminous mat, we prepare a dense grade mix by the same method we build a mat, some 40 or 100 cubic yards per mile, and stock all that over the winter season. That stock pile is very useful and in patch work it might be necessary during the winter time to prevent deterioration until summer comes again and we can get around to reconditioning work. That material always is very useful in that way. Nearly always there are adjacent concrete roads in which blow-ups occur and for a temporary patch by knocking out the jagged edges of this blow-up we fill in with this material. We can make that portion travelable until we can get around and by other means to make more permanent repairs.

On some of our roads that are older and require a little patching but not quantity patching we use a little cold patch mixtures, about ten cubic foot capacity. But we are nearly always ready to have that cold patch material made at our warehouse or yards to try to prevent the men from making the patches in the field. They will invariably get it too rich and possibly get it too high, and they will try to make a little bed and place some of it by penetration method, so the patches made in the field with cold patch mixture are not so successful. But if we can get it made in the yards with more experienced men and then truck it to the places, we're all right. We try to keep the stock piled material ahead and even on some of the older mats we may lay down several carloads of material and then stock pile it, and that stock piled material is nearly always made from the same aggregate and the same asphalt from which the mat was made.

Mr. Houk: Anyone else anything to say on patches?

Mr. Bourne: Washington

In my travels I go through California, Oregon, Washington, and Idaho, and I think that the maintenance departments in many instances are not giving the proper consideration to the low cost types, and if they would prepare the area to be patched as they would for the asphaltic concrete pavements, they would get better results.

Mr. Houk: I agree with you thoroughly. Mr. Jordan, do you have anything to offer on patches?

Mr. Jordan: Alabama

Our bituminous patches consist usually of either filling and leveling of low places, or repairing areas of base failures. The latter group is the one with which we have most difficulty in handling. These failures look very much alike but result from different causes such as poor sub-base material, poor base material, insufficient depth of base, poor drainage, etc. It is essential that the cause of the failures be properly analyzed so that the trouble can be corrected in making the repair. It is difficult to train maintenance foremen to analyze properly and correct these troubles. During the last two years we have had our division materials engineer and division maintenance engineer, with the supervisors, give a good deal of time to the study of the causes of such failures, as well as to methods and materials to be used in the base repairs, and with this a great deal of improvement has been made, but we do not consider the problem solved yet. I might add that nearly all of our patches of this type are on our older roads, as we have had very few failures on the bituminous roads constructed in the last two years, during which time we have given careful attention to subgrade preparation and base construction.

I might add also that on a few sections of our older roads we patched and patched and then had to reconstruct them, illustrating that when the conditions causing the failures occur generally along the section, even though in somewhat varying degree, consideration should be given to reconstruction instead of expensive patches from time to time.

Mr. Houk: I think a good many of our patches are in effect similar to putting new skin over a boil. I would like to have Mr. Jones discuss the methods he uses in Oklahoma for a few minutes, after which we will adjourn.

Mr. Jones:
Oklahoma

I know you are in a hurry. I want to pass on to you one idea on equipment that might be beneficial to some. It is not original with the engineers of Oklahoma but was passed to us by a materials company.

We did have in each of our districts a heavy hydraulic disc that was pulled by a Caterpillar that can rough up the top of a mat so that we can reconstruct it. But in that case we have to haul that disc to the job and then find a Caterpillar that can pull it and waste a day or two getting ready to start. Now we furnish our motor patrol with what we call a saw-tooth blade. The notches in it are two inches apart and two inches deep set at an angle of about 45° across the road, and then it is very easy to start combing the surface or tearing it up just a little so the straight bit can get a hold and cut to whatever depth is required. That is good, for example, in roughing up the top of the road to aerate it. It might have a little water or maybe the mat was sealed before the volatiles got out, and those blades can be carried on the motor patrol.

Mr. McKinnon: Montana — The Conference Committee on the correlation of research wishes to present a resolution for future work.

Mr. Traxler: New Jersey — WHEREAS the Montana National Bituminous Conference recognizes that successful bituminous practice, in all its phases can continue to be successful only if based upon facts established by sound, fundamental research and,

WHEREAS research can attain its appointed goal only if directed by able and sympathetic interests,

NOW, THEREFORE BE IT RESOLVED, that this Conference in its 1937 assembly hereby directs the appointment of a committee of three of its members whose duties shall be:

1. To transmit to and acquaint highway executives with the necessity and desirability of assisting the Highway Research Board, and other agencies in stimulating fundamental bituminous research and in assembling, analyzing and disseminating the resulting research data,
2. And, after obtaining the opinions, suggestions and reactions of the highway executives, to formulate a plan of procedure which shall be presented for the consideration of the Montana Na-

tional Bituminous Conference in its 1938 assembly.

You have heard the resolution. I move the adoption.

Mr. McKinnon: Montana — It has been moved and seconded that the resolution presented by the committee on the correlation of research be adopted. Any discussion? All in favor say "aye." The motion is carried.

Has anyone anything to bring before the closing of this Conference?

Mr. Perry: Iowa — Mr. Chairman, it is probably both appropriate and proper at this time to express a word of appreciation to the Montana National Bituminous Conference for this meeting. It represents a lot of work and without any preliminaries I believe that all the delegates appreciate, and everyone in attendance, what has been done at this Conference.

Furthermore, I believe that everyone is going home with some good, new, workable ideas that they have gathered here at this meeting, so that the value from that standpoint cannot be disputed.

We all thank you very kindly.

(ADJOURNMENT)

Papers Prepared

on

Maintenance of Bituminous Surfaces

for

The Montana National Bituminous Conference

The Maintenance of Bituminous Surfaces

By

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The maintenance of bituminous surfaces may be defined strictly as the work of keeping the surfaces in approximately the same condition as when originally constructed. However, the maintenance program of the Alabama Highway Department includes in addition to this limited work, such additional betterment work as is necessary to accomplish its purpose of preserving the investment in bituminous surfaces and providing for non-skid, smooth and balanced riding on them. Much of this additional work is on the older bituminous roads and consists of reducing the crown, increasing the superelevation on curves, and of slightly widening some narrow surfaces.

The purpose of this paper is to outline the work of the Alabama Highway Department in its effort to carry out this program. In doing this, a general statement will be made first concerning the ages and types of bituminous surfaces, amount of traffic, climatic conditions, a brief outline of the maintenance organization, and then a discussion of methods used.

Alabama maintains 1605 miles of bituminous surfaces. Of this 335 miles is of the so-called high type, most of which is from four to seventeen years old, and which consists principally of bituminous concrete bases with Modified Topeka, Warrenite Bitulithic, or Hot Mixed Natural Limerock Asphalt Surfaces, but also includes considerable hot mixed sand asphalts. The low types are principally double surface treatments, but include 110 miles penetration macadam, all over eight years old, and 150 miles of two inch road mix, or plant mix cold laid surfaces two to four years old. Alabama has not used oiled earth roads due principally to high rainfall and relatively high freight rates.

Traffic on these roads varies from 200 to 3000 vehicles per day with an average of about 600. The average annual rainfall is about 52 inches. Continued rains and dampness for 20 consecutive days in winter, or continued hot and dry for 30 days in the summer or fall is not unusual. Temperature of winter varies from 0 degree to 60 degrees, averages about 45 degrees, and for summer varies from 65 degrees to 100 degrees with average of about 82 degrees.

Maintenance in Alabama is under the supervision of the Division Engineer. The State Maintenance Engineer, who reports to the Chief Engineer, acts with the Division Engineers in an advisory capacity. Each Division Engineer is assisted by a Division Maintenance Engineer who directs the maintenance work through supervisors and superintendents. The forces consist of patrol or section crews for ordinary maintenance, and special or extra crews for retreatments, betterments and reconstruction. Approximately one third of the patrol crews and one half of the extra crews are manned with convict common labor. Patrol crews consist of one foreman and six to twelve men with trucks, patch roller, tamps, hot pot, and small tools, and take care of from 20 to 100 miles of road, grouped geographically and hence usually including some roads of other types. Extra crews consist of a superintendent with foremen, usually ten to thirty men and are equipped with mixes, trucks, motor graders, rollers, and small tools. Each Division has a distributor, power brooms and bituminous heaters. Extra crews frequently quarry, crush, and screen their own aggregates, usually limestone, or utilize aggregate from plants operated in the vicinity by State construction forces.

Before discussing methods used by this organization, mention should be made of the two of its major problems. Until about three years ago little bituminous maintenance work was done except the hand work of the patrol crews, and the sealing of a very few sections with hot bitumen and chips. Hence with about 400 miles of bituminous surfaces over five years old, most of which were rough, and with steep crown and little or no superelevation, and with many fat spots resulting from poor hand patches, one major problem has been that of reshaping and resurfacing these so as to provide for smooth, balanced, and non-skid riding. The other major problem arose out of the construction of 150 miles of two inch road mix or plant mix cold laid bituminous surfaces, coarse aggregate type, three and four years ago which were placed on bases of local chert and gravel most of which proved to be too plastic due to excess clay. Needless to say, failures have been extensive. As will be noted, the former problem has to do primarily with riding qualities while the latter had been one primarily of preserving the investment.

About three years ago Alabama began extensive maintenance work on the former problem. The work on these old surfaces consisted principally of levelling, reducing crown, and increasing superelevation and width on curves and, in some cases, slight widening throughout. Premix cold laid bituminous materials were used on this work and found so satisfactory that the use of premixed material has now been adopted in nearly all the maintenance operations except that of waterproofing a surface.

Three grades of premixed material are now used and are as follows: Coarse leveling, fine leveling, and wearing course. coarse leveling consists of crushed slag or stone from 1¼″ to ¼″ with 3.5 to 4.0 percent bitumen. Fine leveling consists of slag or stone from ¾″ to No. 10 screen with 4 to 5 percent bitumen. Wearing course consists of stone screenings from ⅜″ to dust or slag chips ⅜″ to 16 mesh with not more than 30% sand, and from 4.5 to 5.5 percent bitumen. The sand is usually local and fairly clean and coarse. The bitumen is usually Asphalt RC 2 or 3, or Tar TM 2 or TH 1. The percentages are for Asphalt and do not include the solvent.

These mixes are used when the materials are mixed on the job by State forces, which is the usual procedure. However, cold premixed materials are sometimes purchased from one of several commercial producers operating within the State. In such cases the aggregate is usually slag and the bitumen varies with the process of preparation. Wearing course materials made from natural limerock asphalt of natural sandrock asphalt are sometimes purchased, but are usually more expensive because of higher freights.

The mixing of premixed materials by State forces is accomplished by using 12 to 14 cubic foot capacity cold bituminous batch mixers, or by using concrete mixers. These are usually erected against a 16 to 18 foot vertical bank, as in an old quarry, gravel pit, or cut bank, so that materials can be stored on top of the bank and above the mixer, and so the mixed materials can be dumped from the mixers into trucks. Drying equipment is not ordinarily used, although the department has one large continuous mixer of 50 tons per hour capacity with which a dryer is used. While little difficulty has been experienced with the normal moisture of the aggregate during the hot season, the importance of using dry aggregates is such that every reasonable precaution should be taken to see that aggregates used are as dry as practical.

These materials are used for a variety of purposes varying from hand leveling of a small depression, or repair of a small failure, to widening, leveling, and resurfacing an entire section. It is also used to eliminate slipperiness on bituminous surfaces, and often used in doing small repair or leveling and superelevating work on concrete surfaces.

When these materials are to be used for work more extensive than can be handled by the patrol crew, the following procedure is followed: A study is made of the road by the Division Maintenance Engineer, the Division Engineer and the State Bituminous Engineer, and a program of work agreed on which is then submitted to the Chief Engineer for approval. The importance of thorough study and careful analysis of the condition and needs of the road can not be over stressed.

For performing the work there is assigned to the job an extra bituminous crew equipped with trucks, mixer, motor grader, broom, roller, bituminous tank truck or distributor, or drums, and portable asphalt heater tank equipped with hand pressure spray. The work is done in the following manner: If the shoulder provides suitable base, and the program of work includes widening, as is frequently done on the inside of curves, the base is broomed and primed. Any depressions that will not drain are then filled and tamped with a cured premix wearing course material with sand added for density and with about 4.0% bitumen. Before building up on these they are squegeed with Asphalt RC 1 or 2 and covered with sand or screenings. If the base is then lower than adjoining surface, it is built up to the surface with coarse or fine leveling material as needed.

The road surface is then checked by eye and strings, and stakes set and keil marks made to indicate location and depth of first leveling layer. If the surface is to be built up three inches or more, coarse leveling material is used; if less than 1″, wearing course only is used. Layers are placed wedge shaped with top parallel to finished surface and with a maximum thickness of four inches loose. Each course is rolled and as much traffic as practical put on it before placing the next layer. Before the first course is laid, the old surface is given a tack coat of the same bitumen used in the mix except slightly thinned. The amount of tack coat varies from .05 gallon to .15 gallon depending on the dryness and openness of the surface.

The premix material is then dumped on the road, usually along the center, and moved into place by motor grader with some spotting by hand. It has been surprising how well a competent blade operator can place and spread the material even over irregularly shaped areas. The material is then shaped and rolled. This first course work is done throughout the section before the next course is applied in order to get as much consolidation by traffic as possible.

Succeeding layers are placed as needed, changing to fine leveling or wearing course as the thickness of layer makes necessary. Except in superelevating curves, one layer of coarse leveling is usually sufficient and then fine leveling or wearing course mix is used to further shape the surface as needed. On surfaces where no appreciable change is to be made in the crown or superelevation, and there are few depressions of more than two inches in depth, wearing course only is used except for hand placing of coarse or fine leveling in advance in the deeper depressions. In such cases the wearing course material is placed in two courses. The first by spreading with grader blade so as to just fill depression and then rolled. Then after sufficient traffic has been on the first course, the second course is spread, rolled and sanded.

The above work is incomplete without a sealing operation.

Where premixed material is placed one inch or more thick, a seal should be provided, whether it be on a hand patch or a few square yards, or the resurfacing of an entire section. Unless this sealing is done, water in the lower part of the mix will cause the asphalt to leave the aggregate. The above wearing course mixture does not result in a sealed surface. If the wearing course mix is made sufficiently dense and contains sufficient bitumen to provide a water tight surface it will soon become slippery, and no operation is justifiable that results in a slippery surface. Hence, efforts to make the premix wearing course water tight within itself have been discontinued. The aim now is to make it nonskid, having the density and bitumen content just sufficient to prevent ravelling.

Various methods of sealing premixed bituminous surfaces have been tried and it is now believed that the best method of securing a surface that is both water tight and nonskid, especially on heavy traffic roads, is to place the seal application before placing the wearing course. In such cases, the wearing course must be kept thin so that moisture in it can evaporate. In this method the surface, which has been leveled to the point of applying the wearing course, is treated as follows: If the surface is porous to such extent that the bitumen will drain down into the mixture, it must first be choked. Ususally a light covering of sand or screening will be sufficient. This is allowed to work in under traffic, and then the surface is broomed and Asphalt RC 2 or 3, or Tar TM 2, is applied by squegee method so as to just fill the surface voids. Usually .10 to .20 gallons per square yard is required, depending on the tightness and smoothness of surface. This is then covered with sand or screenings, and maintained under traffic until the bitumen will take no more sand or screenings. The surplus is then broomed off and the premix wearing course is laid, using usually 30 to 40 pounds per square yard.

Alabama has about discontinued the use of seals of hot bitumen covered with chips. The reasons are that this method does not permit of varying the treatment to suit the variation in texture or bitumen content of the surface, and does not improve riding qualities. Also, except where the traffic is light, the chips are frequently soon worn off or torn off and the road becomes slippery.

In eliminating slipperiness, which has developed on some of the older hot mix asphalt pavements, premixed wearing course material has been used more successfully than applications of bitumen covered with chips. On all such work, any depressions are first leveled as outlined above. Then the surface is cleaned and given a tack coat varying from .05 gallon on smooth rich areas to .10 to .12 gallon on any areas that are dry or disintegrating, and to .15 to .20 gallon for sealing any areas recently leveled. Where .12 gallon per square yard or more is applied it is covered with sand. Then the premix wearing course is applied by blading and rolling.

Another problem on many of the older hot mix asphalt surfaces has been the handling of cracks. The majority of these are contraction cracks which develop entirely across the pavement and open as much as ¾″. In some cases additional cracks develop irregularly over the surface. Formerly these were poured with Asphalt AC-6, but now a lean Asphalt sand premix is being used, by brooming the cracks full of this premixed sand. Before filling, the cracks are cleaned and should be dry. After the wider cracks have been under traffic a few days, it is necessary to refill them because of compaction. Immediately after refilling they are painted with cut back asphalt and covered with dry sand. This method is believed to be far superior to that of pouring with crack filler, as it keeps them filled better, and they are hardly noticeable. Poured cracks look bad and are soon wide open to water again.

Alabama has found is necessary to make extensive repairs to some of its low cost roads built a few years ago, and especially to the 150 miles of 2″ plant mix and road mix bituminous surfaces, previously referred to, and which were laid about four years ago on bases containing too much plastic clay. Local failures have been numerous. In repairing these local failures it has been found that it is especially important that careful study be made to determine whether each area can be corrected by adding proper materials to the surface, or whether the area must be cut and reconstructed. Lack of such study has resulted in many areas being built up that later had to be cut out, and in some being cut out that could have been satisfactorily handled by leveling, sealing and surfacing. No fixed rule can be given. However, as a general rule, if there is any indication of lateral movement of the base, or pumping of clay through surface cracks, then the area should be cut out. If these are not evident, the area can usually be built up successfully. The use of careful observation by men experienced on the particular type of road is the best procedure.

If it is decided that the area need not be cut out, it is leveled by applying a tack coat and filling with premixed coarse or fine leveling material, or both. Then after sufficient traffic for consolidation, it is sealed with bitumen and sand or chips, and finished to desired elevation with premixed wearing course material.

If the area is to be cut out, both surface and base are removed, and an effort made to determine accurately the cause of failure. Usually this is either thin base, poor quality base, bad sub-base soil, poor drainage, or a combination of these. Seldom are failures due to the bituminous mat except where the mat is not properly sealed. It is very important that the cause of each failure be ascertained, and that proper steps be taken to remove or offset the case in making the repair. Usually the repair is made as follows: Top and base are removed. Subgrade is examined and any contributory bad soil removed or stabilized with suitable aggregate. To provide drainage, blind drains of tile, stone, or gravel are constructed through the shoulder. It is sometimes necessary to locate these, or construct others, so as to intercept seepage. Formerly, the entire shoulder was removed in many cases and replaced with pervious material to facilitate drainage, but it was found that the lateral support provided by the existing consolidated shoulder was worth much more than any additional drainage provided by this method. The base is renewed with carefully selected or prepared stable material of the same type as the surrounding base. This is carefully compacted in layers to slightly above finished road elevation, and left to traffic until sufficiently consolidated, after which the top portion is removed to the bottom of the surface course. At this time the old surface is removed for an additional width of about 8 inches around the patch. The surface is then primed, and when dry, a hot application of .40 to .45 gallon Asphalt, (AC-10), or Tar, (TH-2), is applied and covered with crushed stone or slag aggregate, (1¼″-½″). While the sealing qualities of this hot application are perferred, sometimes, especially in repairs to road or plant mix surfaces, a premixed bituminous binder course is used instead of this hot application. After a few weeks under traffic, this surface, which is usually about ½″ low, is cleaned and given a seal coat of Asphalt RC-1 or 2, applied by squgee method and covered with sand or screenings, and then built up with a premix bituminous wearing course material, such as mentioned above. Where the hot application is used, the premix wearing course is applied without the operation. After careful spreading and rolling to an elevation slightly above the surrounding surface, it is covered with sand or screenings.

Such repairs are expensive, and hence when failures begin to appear generally along a section, a careful study of such sections should be made to determine as accurately as practical the nature and extent of conditions conducive of failures, and an estimate made of probable extent of future failures. Important in this is the matter of determining whether the causes of failure that have already developed are purely local or obtain generally over the section, even if in slightly varying degree. In the latter case, it is better to make the repairs as few and of a type as inexpensive as traffic service requirements will permit, until the extent of failures is evident, as it is oftentimes cheaper and better to reconstruct such sections entirely than to repair numerous local failures from time to time. If it appears that the failures will amount to as much as eight to ten percent of the surface area, reconstruction is advisable.

This lesson has been forcibly impressed by our experience on the 150 miles of 2″ road mix surface referred to. During the first winter and spring local failures began to appear. Patrol crews were augmented in an effort to repair these as fast as they developed. After considerable funds had been expended trying to catch up with and keep up with the breaks, it was realized that reconstruction was inevitable. Then long sections, totalling in all about thirty miles, were reconstructed, which of course included the sections on which we had done most of our expensive patching.

Such sections, which varied in length from ¼ mile to 6 miles, were reconstructed by extra crews of the maintenance department. At first the 2″ bituminous mat was scarified with the base and these with additional coarse aggregate and sand, were thoroughly mixed. It was found that the type of bitumen in the mat tended to lubricate instead of stabilize the base, and that fine aggregate was needed to stabilize the clay. It was also found that on many sections the amount and nature of clay was such that it was very difficult to stabilize it by addition of sand or screenings. This was true when the clay in the portion passing a 10 mesh sieve was more than 35%. Hence the procedure later followed was to scarify the 2″ mat and blade it into a windrow, from where it was picked up with a small power shovel and loaded into trucks. By exercising care, very little prime and base material was mixed with it. This mat material was then used on other roads as coarse leveling material. Then one or two inches of local sand was bladed over the old base, and a new base of satisfactory material laid thereon, and a double bituminous surface treatment applied.

The Maintenance of Bituminous Surfaces in Wyoming

By

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Before starting this discussion, it might be well to define maintenance and then apply this definition to the surfacing only, as that is the part of the highway with which this paper deals. Thomas M. MacDonald gives the following definition for maintenance: "General highway maintenance is the function of preserving and keeping each type of roadway structure and facilities as nearly as possible in the original condition as constructed or as subsequently improved to produce satisfactory service." This definition, I believe, is generally accepted by all highway engineers. Applying the above definition to surface maintenance simply means keeping the surface in a condition to give satisfactory service without changing the original type of surface by reconstruction or betterments.

The Wyoming State Highway Department pioneered in bituminous surfaces in the Rocky Mountain region, and, therefore, we have various types of oil mats, ranging from a three-inch plant-mix using slow curing oils (SC-3), to those of a one and one-half inch mat using both slow curing and medium curing oils (SC-3 and MC-3). The majority of these thin mats that were built previous to 1934 were laid on grades with very little if any base. We have gotten very satisfactory results from these roads. The maintenance cost has been somewhat high, but has not been prohibitive by any means. The traveling public has had the use of these dustless roads for quite a number of years, and the maintenance cost has been considerably less than it would have been in maintaining a gravel road.

Wyoming has practically abandoned patrol maintenance and uses gang maintenance instead. The reason for this change was both economy and efficiency. We in Wyoming feel that the change has been more than justified. The entire State Highway system of 3,600 miles is maintained out of thirty-one permanent maintenance stations, with about eight sub-stations where summer maintenance only is done. The sub-stations are primarily located on our mountain roads that are not kept open during the winter months. At each of the permanent stations there are from four to ten regular employees that are paid on a monthly basis. These are picked men that have been chosen from several hundred over a period of from ten to fifteen years. All are capable of doing almost any type of maintenance work. These men are picked on a basis of efficiency, cooperation, loyalty to the Department, and courtesy to the traveling public. The regular forces are augmented by additional laborers that work on an hourly basis in case of emergency, such as severe snow storms, wash outs, and seal coat work where additional flagmen are needed. At each permanent station there is sufficient maintenance equipment for the size of the crew. The major equipment consists of four-wheeled drive heavy-duty trucks, one and one-half and two ton trucks, pickups, motor graders, pull graders, tar pots, oil distributors, tanks for oil storage, tanks for hauling oil, and mowers for weed cutting. In addition to the above, there is a $\frac{3}{8}$ yard shovel and some two or three differential-driven sand or chip spreaders in each district.

Wyoming's maintenance setup is somewhat different from that of other states, in that we operate without a general maintenance engineer. Our maintenance is the responsibility of the district engineer.

The state is divided into five districts. Each district engineer is directly responsible for all the work in his district. In each district there is a maintenance supervisor that is in direct charge of all maintenance. Under him are the crew foremen at each of the maintenance stations and all other maintenance employees. The maintenance supervisor reports direct to the district engineer, and he to the highway superintendent or to the main office. We have found this system very satisfactory, as the district engineer is responsible for both construction and maintenance, and the buck-passing from the construction to the maintenance department, or vice versa, is completely eliminated. We do, however, lose an important direct contact between districts that a maintenance engineer would give in passing on ideas from one district to another.

Everyone agrees that the comparison of maintenance cost of the same type and standard of road between states means very little at the present time. This is due to the fact that practically every state has a different method of keeping costs. Work that one state charges to general maintenance may be charged to reconstruction or betterments in other states. The reason for this difference may be merely in the accounting system, or it may be due to the legislature's ear-marking certain funds for maintenance or other specific purposes. If a state has considerable funds ear-marked for maintenance purposes, that state's maintenance cost in general will show high per mile. In order to properly use these funds, it is necessary to charge more or less reconstruction or betterments to maintenance accounts. On the other hand, if the maintenance budget is small, it may be necessary to charge work that is direcly a general maintenance charge to reconstruction, etc. The American Association of State Highway Officials, recognizing this fact, appointed a committee some three years ago to work out a practical accounting system that all states could approve for general maintenance cost keeping. After about two years work by this committee, they asked the Bureau of Public Roads to appoint a full time man for this work, to hold regional meetings to try to bring the states together. There has been a lot of good work done, and it is hoped that in the next year they will have something definite to give the states on cost keeping or accounting.

In Wyoming, general maintenance costs are divided into eleven general heads of accounts. These are: Supervision, Right of Way, Signs, Road Bed, Bridges, Surface, Drainage, Snow Storage, Snow Removal, Ice and Floods, and Miscellaneous. It might be interesting to note here that center striping in Wyoming is charged to the Sign account. In surface maintenance is included such work as dragging, blading, patching, re-processing and re-sealing the oil mat. It also includes all materials such as gravel replacements, additional oil for re-mixing when needed, and all cut-back asphalts for re-sealing. I might add that all equipment cost, including depreciation, repair cost which includes not only actual repairs but also shop overhead), and all operation costs of maintenance equipment is charged to the maintenance of our roads. In other words, we are endeavoring to the best of our ability to get all cost into our general maintenance that should go there, and to eliminate from our general maintenance all that should not be charged there.

Surface maintenance cost last year, 1936, averaged 52½% of the total maintenance cost. In individual counties, it ran as low as 29% of total cost and as high as 69% of total cost. Another comparison that might be of interest is of two maintenance projects joining on the same road and carrying the same amount and type of traffic. One shows a surface maintenance cost of 3% of total. The other shows a surface maintenance cost of 80% of total. The one with the low surface maintenance cost is on a well graded and well drained road with a good base and a two and one-half inch SC-3 oil mat sealed with a chip seal. The other is on a low grade with poor draniage and insufficient base through an irrigated country, but has substantially the same type of oil mat without the chip seal. I might add that the total maintenance cost of the first mentioned project was less than $130 per mile, and for the latter project more than $300 per mile.

The methods used in maintaining bituminous surfaces are about the same, regardless of type. It may be a two and one-half or a three inch MC-3 mat on a well graded and well drained road bed with an excellent base, or it may be a one and one-half inch mat of SC-3 oil on a low grade poorly drained and with practically no base. In both cases, the maintenance methods will consist of pre-mix patching, cut-back and size rock patching, scarifying, re-processing, and re-sealing. Naturally, the mat on the well graded and well drained road with an excellent base will require only a small portion of each type of work as does the mat with the low grade, poor drainage, and insufficient base.

We in Wyoming have found that there is a definite place in surface maintenance of the bituminous roads for both pre-mix patching and a cut-back asphalt patch with sized rock. Where there is a very shallow hole or a low depression, cut-back patches work very satisfactorily and are preferred to a pre-mix patch. However, on a deep hole two or three inches a pre-mix patch is generally the best. On shoulder or edge patching of our thin mats (mats of one and one-half inches or less) the cut-back patches stand up much better and are used in the majority of cases. We have found it very essential, therefore, to have a stock pile of pre-mixed material on hand during the spring when the frost is leaving the ground and we are having our spring storms. On narrow roads especially, the pre-mix can be used to fill holes even in wet weather to give a safe road for traffic until such time as weather conditions will permit a more permanent repair. For cool weather, a cut-back patch is the only one that is satisfactory, and is used almost entirely during winter months.

On stretches that roll up or corrugate and on places that have ravelled to such a point that patching is not economical, we scarify and re-process, adding oil where necessary. Both slow curing SC-3 and medium curing MC-3 are used in this re-working, dependant on the original construction and the type of material being re-worked. On an average, there is about 100 miles of re-processing done each year, out of approximately 2600 miles of oil roads in the state. Most of this re-construction is on old projects that were oiled in the early days of oiled roads. We have not found a great deal of difference in the maintenance cost of one and one-half inch or two and one-half inch oil mats when laid on the same type of road bed and base, the main difference being that the two and one-half inch mat has considerably more healing action than does the one and one-half inch mat. This is especially true through a farming section where the edges of the mat are used by livestock traffic.

Most of the Wyoming roads are sealed with the so-called paint seal. However, there are approximately 150 miles of chip seal. This is practically all on roads that carry heavy traffic, mostly on well graded roads having a good base and a two and one-half inch mat. On the roads that have a chip seal and a good shoulder with flat slopes, we have had practically no trouble. However, on the narrow roads where the mat is out practically to the shoulder line, we have had some edge trouble during spring storms. These are not failures of the mat or base, but are more subgrade failures due to the lack of latteral support for heavy loads running close to the shoulder line. The chip seal costs on an average of $690 per mile in our state.

On paint seals we use both RC-1 and RC-2 rapid-curing cutback. However, when RC-1 is used, it is generally necessary to cover with a light coat of clean, sharp sand, about ten pounds to the square yard being used. This year, a special RC-1 is being used on paint seals that are not to be sanded. This is a material that will both penetrate into the mat and dry so as not to pick up under traffic in about five hours. Both of these features are very necessary in order to avoid having a portion of the seal set up on the top of the mat and cause slick places during wet weather. When such condition develops on our roads, it is corrected by sanding as soon as possible.

In conclusion, I might say that in Wyoming the major maintenance feature is a surface maintenance. We are endeavoring to keep the surface of our roads in safe condition for the traveling public at all times. This is the part of the highway that is actually used by the traffic, and we feel that it is much more important to keep these surfaces in a smooth, safe condition than it is to have a beautiful roadway condition with a surface that is not safe for the high speed cars that we have on our roads today.

Maintenance of Bituminous Surfaces

By

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Within the last seven years the State of Kansas has built a large mileage of bituminous surface. Needless to say, the construction practices have varied, some practices being discontinued and others after proving their worth being adopted.

To date we have two types of bituminous surface under Maintenance; namely, bituminous mat surface and a light surface treatment known as oil penetration. The first type consists of eight to fifteen hundred tons of either coarse graded, or densely graded aggregate giving a finished thickness of approximately 2½ to 3 inches. The second type, as stated, is a light bituminous surface treatment and the thickness is rarely more than ⅜ of an inch. The mileage of both types in June, 1937, is as follows: Bituminous mat surface 2053.1 miles and the light type bituminous surface treatment 1223.4 miles, making a total of 3276.5 miles of bituminous surface under state maintenance. This mileage is slightly more than one-third of the total mileage in the State Highway System.

The maintenance of bituminous surfaces is not a thing for which rules can be written in black and white. It requires constant thought, and a good maintenance man must have imagination enough to forsee conditions and take steps to prevent many of the failures that may arise.

Kansas has established a combination of the Patrol System and the Gang System of maintenance. There are approximately 120 bituminous maintenance sections in the state and a sectionman, and helper, is responsible for the routine maintenance of his own section. Each section will average approximately thirty miles in length. In addition to the sectionman we have district crews and Division crews.

The District crew consists of five to ten men and will work entirely out of the District Headquarters. They are equipped with one 300-gallon two-wheeled trailer distributor, two light duty trucks, 3½ ton pull type roller and all necessary small tools.

The Division crew is equipped with an 800-gallon distributor, approximately five trucks, one boiler, rollers and incidental tools. Also, they have at their command patrol graders or pull type blade graders. The personnel and equipment as outlined above apply to bituminous surface maintenance only. The average mileage covered by the district crew is 175 and the average covered by the division crew is 500 miles.

The sectionman and his helper are responsible only for the section assigned to them, and the maintenance operations are broken down into several component parts, such as surface, road bed, drainage, structures and bridges, right of way, and signs. It is his duty to especially maintain the surface and prevent pot holes, raveled edges, corrugated conditions and shoulders.

From our maintenance experience, during the past seven years, it is our opinion that surfaces built with the present type of bituminous binders will not last for more than an average of a few years. At that time maintenance costs become prohibitive because the sectionman can not possibly keep the surface in a good condition.

There apparently are two causes for this uniform failure throughout the state. First, the bituminous binder loses its life or binding qualities and becomes dry and brittle. Second, the subgrade is unstable due to low grade line, poor drainage, intercepted rock or shale ledges, or a combination of all.

During the past two years we have experimented with maintenance forces in trying to correct both the above named failures in one operation. This operation consists of scarifying the existing bituminous surface and sub-grade to a depth of at least six inches. This, of course, includes a large portion of subgrade soil. The material is mixed by blades or discs, or other suitable equipment and relayed and compacted by the use of the sheeps-foot roller. All unfavorable conditions may be corrected by this one operation, such as deepening the drainage ditches, narrowing down the traveled way and correcting the surface condition, which is usually very much out of line. After the surface has been scarified and mixed with subgrade soil and relayed, sand gravel or crushed stone is added and traffic allowed to use the highway. It is then maintained for a period of two weeks to two months as a dry surface, after which a light type bituminous surface is constructed.

The light type bituminous surface consists of penetrating the prepared grade with approximately five-tenths gallon per square yard of an SC-2 or an MC-2K (Kansas specifications cutback asphalt with viscosity range of 100 to 300). After the first application has penetrated the sub-grade, an application of approximately 0.3 gallon per square yard of SC-6 or SC-7 or an MC-2 or MC-3 oil is placed and immediately covered with cover material, then the whole surface is rolled and opened to traffic.

After two years of trial it is our opinion that this method is the best method to use after the bituminous surface has lost its life and becomes dry, raveled and pot-holed. We do not presume to say how long this type of reconstruction will last, but expect it to be good for a few more years or until such time as the renewed bituminous binder loses its binding qualities after repeated sealing operations.

Our standard method of sealing a dry bituminous surface is to apply approximately 0.25 of a gallon of bituminous material to the surface and cover it immediately with a cover material which may consist of sand gravel, crushed stone, or chat. Usually this cover material is windrowed uniformly for the length of the project and is shifted on the fresh oil by a pneumatic tired patrol grader. On narrow road ways where it is not possible to place a windrow of cover material at the standard rate of 125 cubic yards per mile we use the sand spreader; however, a close check of costs discloses that the sand spreader method costs from $40.00 to $80.00 per mile more than the windrow method.

We have learned that after about four sealing jobs on one bituminous surface section that further sealing is not effective for more than three months. This is due to the fact that the bottom of the original bituminous surface is drying out and the bituminous binder has last its life or binding qualities so that additional material on the top is merely a temporary corrective measure. If the asphaltic binder would retain its binding qualities indefinitely, maintenance operations and costs would be materially reduced.

In regard to the second major cause of bituminous surface failures, namely, unstable subgrades, we have tried various corrective methods, perforated pipe and rock drains have been installed, crushed stone bases have been installed, of a thickness of not less than six inches, subgrade has been stabilized by the addition of mineral aggregate, and drainage ditches have been cleaned.

In the western two-thirds of our state soil conditions are not ordinarily feared as a cause for probable failure. In the eastern third we have learned that a road should be built to standard grade before a bituminous surface is placed on it, otherwise, we may expect a higher maintenance cost.

Accumulated maintenance costs from July 1, 1936 to April 30, 1937, are as follows: Bituminous mat surface $416.46 per mile, light type bituminous surface treatment $507.71 per mile. This cost is considerably higher than the per mile maintenance costs of bituminous surfaces of early construction. The increase in maintenance cost, in our opinion, is due to the two causes as enumerated previously in this paper, namely, the loss of the binding qualities or life of the bituminous binder, and the second, unstable subgrade conditions.

Maintenance of Bituminous Surfaces on Nebraska Highways

By

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This paper covers the maintenance report for Nebraska submitted to the 1936 Montana Bituminous Conference, with some additions and minor changes. Tables I to X showing bituminous surface mileage and costs have been brought up to date and Tables XI to XIV have been added to the table presented last year.

MAINTENANCE ORGANIZATION

The maintenance organization of Nebraska is supervised by a Maintenance Engineer who is directly responsible to the State Engineer. The State is divided into eight districts each of which is composed of about ten or twelve counties. Each district is in charge of a District Engineer who supervises both construction and maintenance and who is responsible to the Maintenance Engineer for the maintenance activities in his respective district.

The highways in each district which are eligible for State maintenance are divided into patrol sections which vary in length depending upon the type of surfacing, traffic, topography, and soil. Where a nearly continuous length of bituminous surface has been constructed these patrol sections may cover as much as fifty miles in length, but where isolated projects of bituminous surfacing have been constructed each project may constitute a patrol section. Each District Engineer generally has about six Chief Patrolmen under his supervision who are in direct charge of the maintenance for a group of assigned patrol sections.

ORGANIZATION AND EQUIPMENT FOR ROUTINE MAINTENANCE OF BITUMINOUS SURFACES

The routine maintenance of bituminous surfaces is performed by a crew of from two to five men, depending upon the length of the patrol and the season of the year. Each crew is equipped with a truck, roller, asphalt kettle, and all tools necessary for repairing surface and shoulder failures. Small quantities of asphaltic oil are stored in barrels at each of the patrol sheds. Patching material is available either from stock piles placed at intervals along the road or from the patrol sheds.

ORGANIZATION AND EQUIPMENT FOR SPECIAL MAINTENANCE OF BITUMINOUS SURFACES

Special maintenance of bituminous surfaces is performed by crews assembled from the district in which the work is to be performed. The equipment used is also assembled from the district in which the work is done except that in a few districts a distributor is sent out from another district or from the Lincoln Supply Base.

The major equipment used in special maintenance work which is not definitely assigned to a particular district, but is available to be sent out when and where needed, is composed of two distributor trucks, six trailer distributors with two tank trucks each, four aggregate spreaders, several windrow gauges, and a tank car heater for each distributor unit. All other major equipment used such as motor graders, ''cats,'' and blades is assembled from the district in which the work is done.

ORGANIZATION POLICIES COVERING MAJOR MAINTENANCE REPAIRS OF BITUMINOUS SURFACES

On bituminous surfacing projects where major maintenance work is involved the Maintenance Engineer inspects the project with the District Engineer and a decision is made as to the length of surfacing requiring major work. The District Engineer then prepares estimates of material required and a summary of the proposed method or methods of repair and submits this information to the Maintenance Engineer for approval.

On many of such projects the Maintenance Engineer requests the Division of Tests to make a study of the failure or failures on the project, determine the cause, and propose a remedy. An engineer from the Division of Tests then makes a detailed inspection of the project, designates points where samples should be taken, and makes notes on the types of failures.

The Division of Tests classifies the failures as to surfacing or base failures and, after the samples are analyzed, prepares a detailed recommendation sheet with one or more methods of treatment which lists the materials and proportions required for making the proposed repairs. This information is submitted to the Maintenance Engineer who makes the decision as to the method and extent of the major repairs.

Major repair work is generally supervised by the Chief Patrolman or Resident Engineer, but when a considerable amount of work is necessary or when specialized work is involved, a Project Engineer, who is specially trained and has had considerable experience, is designated to take charge of such work.

All materials used in maintenance repair work other than routine are submitted to the Testing Division for test and approval.

MILEAGE OF BITUMINOUS SURFACES

The total mileage of bituminous surfaced roads under maintenance in Nebraska as of January 1937 was 882 miles, which was composed of 598 miles of bituminous mat, 263 miles of bituminous sand and 21 miles of surface treated stabilized soil base course. New construction in 1937 will increase the mileage of bituminous mat by approximately 162 miles and the bituminous sand by approximately 15 miles, and will add 137 miles of surface treated stabilized base. This will place approximately 1196 miles of bituminous surfaced roads under maintenance by the end of 1937.

All mileage of bituminous surfacing in Nebraska is given routine maintenance. Approximately one-half of the total mileage has received special maintenance other than construction sealing.

Table I shows by years the number of miles and the kind of bituminous surfaces constructed in Nebraska and the approximate mileage given special maintenance. This table groups the surfacing under the two headings, Bituminous Mat Surfaces, and Bituminous Sand Surfaces. The table also shows the type of special maintenance given, cause of failures, and whether the work was done with construction or maintenance funds.

TRAFFIC STATISTICS

The correlation of traffic statistics and maintenance costs is a debatable question and a problem that is difficult to solve.

In studying the relation of maintenance cost to traffic count several factors must be taken into consideration. Due to the many types of bituminous surfaces that are constructed, it would first be necessary in making a comparison of traffic count and maintenance cost to limit the comparison to some one type of surfacing. The maintenance on a cheaply constructed surface should not be compared with a better constructed surface having the same traffic count. In the second place, it is necessary to differentiate between the number of vehicles using a road and the class of traffic or traffic load the surface must support. And in the third place, it is necessary to take into consideration climatic variations such as prolonged periods of high temperature or wet weather.

On several bituminous sand roads in Nebraska considerable damage has been done by heavily loaded trucks operating during prolonged periods of hot weather. These same trucks could pass over the same road thousands of times during periods of normal temperature without causing appreciable damage. The same is true for bituminous mats whose subgrade material, due to low grade or to insufficient drainage, has become softened by prolonged wet weather.

No doubt there is some relation between maintenance cost and traffic count, but in Nebraska it is not definite or fixed and maintenance cost does not necessarily increase with the traffic count on poorly constructed or light traffic surfaces but if a surfacing is inadequate for the maximum traffic load to which it may be subjected, the maintenance cost will probably increase in a much greater ratio than the traffic count. On the other hand, if the surface and subgrade are adequate for the most severe type of traffic load, the cost of maintenance should not be materially different for either a high or low traffic count.

When properly analyzed and applied, a traffic count should materially assist in selecting an economical type of surface but it does not predict accurately what may be required of the highway after it is improved. In the past Nebraska has not had a complete traffic count but at the present time an extensive traffic survey is being conducted by the Department of Roads and Irrigation, in cooperation with the U. S. Bureau of Public Roads, as one phase of the Highway Planning Survey. The traffic counts shown in Tables II to XIII inclusive, of surface maintenance costs were compiled from incomplete data obtained during the past year.

METHODS OF COST KEEPING

The methods used in cost keeping for bituminous roads are in general the same as for other types of roads. All maintenance is divided into the following classes: Class 1, Surface Maintenance; Class 2, Roadway Maintenance; Class 3, Equipment Maintenance; Class 4, Office Administration; Class 5, Miscellaneous; Class 6, Supply Base Maintenance; Class 9, Markers and Sign Refinishing, and Stocking Department.

Each of these classes is subdivided into a number of separate items pertaining to the class of work done. Under Class 1, Surface Maintenance, appears the following items for surface maintenance on bituminous roads:

> Item 6, Bituminous Mat or Oiled Sand Road Repairs. This item only covers routine repairs. It includes the patching of holes, the repairing of small surface breaks and raveled shoulders, and the dragging or blading of the oiled surface if such is required.
>
> Item 16, Construction of New Oiled Surfaces. This item includes the first seal coat if placed within ninety days after the mat is completed or if placed in conjunction with the construction of the mat but it does not include the preparation of the grade.
>
> Item 19, Preparation of Grade Preparatory to Oil Construction. This item also includes the construction of new base courses under existing bituminous mats.
>
> Item 20, Bituminous Mat or Oiled Sand Major Repairs. This item includes the reconstruction of the surface, and covers the operations of tearing up, remixing, and laying down. It also includes the addition of any new bituminous products or aggregates (including fillers) that may be required. This item also includes repairs made to existing base courses.
>
> Item 21, Seal Coating Oiled Roads, Including Cover Material when Applied in Conjunction with Sealing. This item does not include minor sealing of small areas or patches as this work is included in Class 1, Item 6,

and it does not cover a first seal coat placed within ninety days after the mat is completed as this work is covered by Class 1, Item 16.

Maintenance costs are also listed by commodities in addition to being classified by Class and Item.

Prior to 1936 a systematic record of the mileage of bituminous surfaces receiving special maintenance was not kept. This information was available only in inspection reports and condition surveys of the bituminous surfacing.

During 1936 a systematic record of the major repairs or special maintenance was kept for the first time. This type of record is very necessary in comparing maintenance costs and in developing information covering surfacing which requires special treatment.

A copy of the forms used by the men in direct charge of special maintenance work on bituminous surface follows Table XIV. Table I-A shows the total mileage of special maintenance in 1936 for each of the groups shown in Table II to XIII and also the mileage of special maintenance for all other bituminous surfaces which are not included in these tables.

COMPARATIVE MAINTENANCE COSTS FOR BITUMINOUS SURFACES

Tables II to XIII inclusive show construction and maintenance costs for bituminous surfacing projects in Nebraska. Data for all bituminous surfacing projects can not be shown as some patrol records include several types of surfacing. Of the total 638 miles under maintenance in 1936 these tables cover the maintenance costs for a total of 451 miles.

The surface maintenance costs shown in these tables include all maintenance of the surface except equipment maintenance and depreciation, administration, and miscellaneous expenses.

The items not included are chargeable both to surface maintenance and roadway maintenance. The last column of the tables gives the average total maintenance cost per mile per year as shown by the Auditor's Statement and includes these items as well as all items of every kind representing a maintenance expenditure on the patrol.

The number of years shown under the column headed "Number of Years Maintenance Cost Recorded" dates from the time the Maintenance Department assigns a new patrol number or makes separate maintenance charges on the new construction. In many cases several months may elapse after completion of the construction work before maintenance charges are started.

The costs shown for surface maintenance does not always give a true picture of the amount of work that may have been required on a patrol. Very little surface maintenance has been required on the major portion of several patrols that show fairly high surface maintenance costs due to the expense incurred in repairing a comparatively short section which had been built on a base that was unsatisfactory at the time the mat was constructed.

The following are a few approximate average costs exclusive of engineering or administration for typical maintenance operations in Nebraska: (1) A cost of $0.01 per square yard per 0.1 gallon applied for sealing with MC or RC asphaltic oil and covering with sand or gravel from the roadside. (2) A cost of $0.012 per square yard per 0.1 gallon applied for sealing with MC or RC asphaltic oil and covering with shipped-in cover material. (3) A cost of $50.00 per mile for scarifying and reshaping half of the depth of bituminous sand surfaces constructed with SC asphaltic oil. (4) A cost of $200.00 per mile for scarifying, remixing, and reshaping the full depth of bituminous sand surfaces constructed with SC asphaltic oil. (5) A cost of $600.00 per mile per inch of depth for reconstructing bituminous sand surfaces 21 feet in width including the addition of filler and MC-2 asphaltic oil. (6) A cost of $400.00 per mile per inch of depth for reconstructing bituminous sand surfaces 21 feet in width including the addition of RC-2 asphaltic oil but without the addition of filler. (7) A cost of from $200.00 to $250.00 per mile for tearing up and relaying bituminous mats constructed with SC asphaltic oil which do not require the addition of aggregate or asphaltic oil.

The summary of average maintenance costs for all types of bituminous surfaces given in Table XIV was compiled from the weighted averages of expenditures shown in Tables II to XIII inclusive.

ANALYSIS OF FAILURES

The most common failures of bituminous surfaces in Nebraska may be divided into three broad classes: (1) failures of the bituminous wearing surface, (2) failures of the bituminous mat, and (3) failures of the subgrade or base.

Failures of the bituminous wearing surface are usually caused by a low bitumen content in the mix or by the type and action of traffic. The bitumen may lack cementitiousness or it may not adhere to the aggregate because of some surface characteristic of the aggregate. Bituminous sand roads on which SC types of asphaltic oils are used are subject to surface disintegration due to hoof marks of cattle and horses. Properly aerated MC or RC asphaltic materials in bituminous sand are not subject to this action except immediately after construction. Tractor wheels and crawler-type tractor trucks and some types of farm machinery cause surface failures on short sections of bituminous surfaces.

Failures of the bituminous mat should include all failures within the mat that might occur had the mat been placed on a solid foundation. The most common cause for this type of failure is a deficiency of bitumen which allows the mat to disintegrate due to traffic load and impact.

Other failures of the mat which may be due either to faulty design or construction include: the use of inferior or improperly graded aggregates including fillers; the wrong type, or an excessive amount, of asphaltic material; the use of an inferior asphaltic material; and the presence of moisture in the mat. Excessive cracking of a mat may result from a deficiency of bitumen even though the surface of the mat is sealed. Failures of mats due to the presence of moisture in the mat are common but not as frequent as is generally thought. A number of failures classed as moisture in the mat are in reality due to moisture between the mat and the subgrade. Failures due primarily to an excess of bitumen are rare.

Some failures have occurred due to lack of aeration where cutbacks have been used and due to the increased use of MC and RC asphaltic oils, even though special precautions are being taken to insure thorough aeration during construction, there is still some possibility of an increase in this type of failure. This will be particularly true where construction is continued during cold weather. The consistency of the asphalt in place in the mat, the proportion of asphalt and material passing the 200-

mesh sieve in the mix, and the fineness and surface texture of the material passing the 200-mesh sieve are the main factors to be considered in the design, construction or reconstruction of bituminous mixtures containing smooth sand or gravel aggregate graded to produce dense mixtures.

Failures of the base and subgrade are the most common cause for the need of special maintenance and this class of failures is the most difficult to handle. Failures of the mat invariably occur after a failure of the base. Any change in the dry bulk density of the base or subgrade is immediately reflected in the smoothness of the bituminous surface. A change in density may be due either to shrinkage or to swelling of the subgrade or base.

Small changes in moisture content often cause a considerable decrease in the supporting power of the subgrade or base. A small increase in the moisture content of expansive types of soils (clays and silts) may be sufficient to bring the soil to the critical moisture content, while a small decrease, as low as two per cent, is sufficient to cause non-expansive soils (sands) to lose the greater part of their supporting power. The decrease in moisture content of sand subgrade has caused extensive failures on bituminous sand roads in Nebraska during the past two years.

Subgrade failures due to frost boils and soft spots caused by drainage interference are comparatively few in number but they generally require a considerable amount of investigation in proportion to their extent in order to make permanent repairs.

Another type of failure which occurs in bituminous surfaces in Nebraska that has not been previously mentioned is a failure that occurs in the plane between the bituminous mat and the base or subgrade. This type of failure may be due to several causes. A thin layer of loose material may be present under the prime coat or between the prime coat and the mat which may have resulted from the construction method used, or to the presence of loose material under the mat caused by vibration or impact. There may also be a lack of frictional material at the bonding surface due to the lack of base stabilization, faulty design, or to segregation during manipulation. Failures due to these causes may appear at any time of the year and are not dependent on moisture conditions.

Accumulation and condensation of moisture vapor directly under the mat causes a separation of the mat and base, and results in slippage, shoves, and corrugations in the bituminous mat. This condition is very often attributed to moisture in the mat proper. Displacement of the mat from this cause is most apparent in thin mats during a long period of hot dry weather. This type of failure may occur and continue to occur while the subgrade and mat are quite stable.

After failures are apparent in a bituminous surface it is not always possible to immediately make permanent repairs such as an analysis of the condition might indicate was necessary. It is often necessary to make temporary repairs due to lack of sufficient funds, inability to obtain suitable equipment, the large volume of maintenance to be taken care of, or to the lack of suitable detours.

CORRECTION OF FAILURES

ENGINEERING POLICIES AND FIELD METHODS USED

In Nebraska previous to 1935, it was the policy to seal bituminous surfaces only when considerable indication of raveling was apparent. All sealing done prior to 1935 was done as a maintenance item. In 1935 all mats, which were constructed in 1934 and not sealed immediately as a part of the original construction, were sealed with construction funds. In 1936 all but three of the projects constructed in 1935 were sealed as part of the construction. Of the mats constructed in 1936, 40 miles were sealed in 1936 as part of the construction and 95 miles will be sealed in 1937.

In the maintenance of bituminous mats, the present policy is to seal all mats which show deficiency in bitumen immediately after construction.

For mats having a high density with smooth tight surfaces a seal coat of RC-2 or RC-1 is applied at the rate of 0.15 to 0.20 gallon per square yard. This is covered with about fifteen pounds per square yard of medium sand gravel or armor coat aggregate. On mats containing coarse material or having a rough surface, an RC-2 or RC-3 seal coat of 0.20 to 0.30 gallon per square yard is applied and covered with approximately twenty-five pounds of coarse concrete aggregate per square yard.

Prior to 1936, all cover material was stockpiled in small piles located at short intervals along both shoulders. After the application of oil this was hand spread over the surface, however, a uniform coverage was not always obtained by this method. The State is now using sandspreaders which are pushed by the trucks hauling cover material, in a backward direction, so that the sand is spread ahead of any equipment passing over the freshly oiled surface. The aggregate is dumped directly into the spreaders and is spread evenly over the surface. This method appears much more satisfactory than the hand method.

On bituminous sand surfaces which were originally constructed with SC-3 asphaltic oil and which have satisfactory stability, MC-2 asphaltic oil is used for sealing. Generally 0.20 gallon per square yard is applied but this quantity must be varied with the season of the year. The cover material used on sealing of bituminous sand surfaces is blow sand which is usually obtained from the roadside. The cover material is not applied until after the penetration of the asphaltic oil is about completed and is then applied in excess of the amount required.

On bituminous sand surfaces originally constructed with cutback asphalts either MC-2 or RC-2 is used as seal material. These surfaces are usually very hard on the surface and subject to considerable cracking due to the lower three inches of the mat remaining soft. The principal reason for sealing these surfaces is to prevent the entrance of sand into the cracks which forms a layer of separation between the upper ½ to ¾ inch of surface and remainder of the mat. Entrance of surface moisture into these cracks has caused no apparent damage during a period of six years.

The reworking of bituminous mats is divided into two groups: those which have had little or no special maintenance, and those which have had considerable special maintenance and are again in need of considerable special maintenance.

Bituminous mats which have had little or no special maintenance and which have developed considerable wrinkling or subgrade displacement are torn up, remixed, the base allowed to dry, and then relaid if the bituminous aggregate appears to contain sufficient asphaltic binder to allow the mat to compact. If the mat appears deficient in bitumen, samples are taken at 1000 to 1500-foot intervals, analyzed, and compared to the original sample data for the particular section. RC-2 asphaltic oil is added to the material found deficient in binder for mats originally constructed with SC asphaltic oil. For mats where MC asphaltic oil was originally used, MC oil is added in maintenance operations. If the mat is relaid without the addition of oil, it is generally sealed immediately.

Mats which have had considerable special or routine maintenance and which again need considerable special maintenance are now reconstructed in a different manner. The mat is torn up and stockpiled or windrowed on the shoulders and the subgrade stabilized. This stabilization is based on the subgrade samples taken prior to the original construction or on samples taken prior to tearing up the mat. Generally a stabilized soil base course is constructed using new materials. In most cases it has been found more economical and more satisfactory not to use binder or other material from the subgrade in the construction of stabilized soil bases which are to be constructed on expansive types of subgrade soil. The stabilized soil base is constructed to a thickness of three to five inches on types A-6 or A-7 soils depending on the height of the fill and the drainage conditions. The depth of stabilization is based on engineering judgment rather than on any engineering formula. Bituminous stabilization is resorted to on sandy and silty soils which are economically suited for that purpose. The depth of this stabilization depends on the quantity of the material in the subgrade soil that passes the 200-mesh sieve. A three-inch depth is generally sufficient where the subgrade soil contains twenty to forty per cent of material passing the 200-mesh sieve. A four to five-inch depth is required when the per cent of material passing the 200-mesh sieve is between ten and twenty per cent. Stabilized gravel bases after compaction are primed with MC-1 asphaltic oil. Bituminous stabilized bases are not primed. The gradation of the bituminous mat is then rectified by the addition of the proper materials and the asphaltic oil content is corrected by the addition of the proper asphaltic oil.

The reworking of bituminous sand surfaces is materially different from the reworking of bituminous mats due to the nature of the subgrade material and the greater thickness of the combined base and surfacing.

Bituminous sand surfaces which are deficient in asphaltic binder are reworked to a depth of two to three inches and after adding the proper quantity and type of asphaltic oil are remixed. Reworking to a depth of less than two inches is an invitation to early failure due to slippage of the top layer on the construction layer below caused by lack of sufficient depth of uniform material to transmit the shearing action of the loaded area.

Bituminous sand surfaces which are low in stability and which have been built on a dry sand subgrade and contain little or no material passing the 200-mesh sieve must have their stability increased to give better load distribution. This involves complete reconstruction and usually the addition of filler material.

Bituminous sand surfaces which have the proper asphalt content, stability, and density, and which fail due to displacement of the subgrade may be reworked to restore the proper cross section as a temporary maintenance operation.

If the failure was caused by the loss of moisture in the sand subgrade and the moisture content returns to normal (between three and five per cent) this type of maintenance is effective.

Some of the early mats constructed in Nebraska were only one and one-fourth to one and one-half inches in thickness and when these mats are torn up approximately one-fourth inch of the base material is incorporated with the mat. This material, together with about one-fourth inch of material added by seal coating, increases the thickness of the reworked mat about one-half inch.

As a policy, the thickening of mats is not intended to accompany reconstruction, however, after a mat has been torn up a second time, the addition of gravel is necessary to correct the gradation. The strengths of reworked mats are usually much higher than for mats originally constructed with SC asphaltic oil. This is due to the use of RC asphaltic oil in the reconstruction which fluxes with the SC asphaltic oil and produces a heavier residual asphalt in the mat.

It has been found necessary on several bituminous mats to seal surface cracks which were caused by shrinkage of the subgrade. This shrinkage was probably due to an unusually severe winter and the extreme heat early in the season. These cracks occur chiefly on mats where the stability of the bituminous aggregate was very high and the bitumen content low.

SPECIAL METHODS AND MATERIALS USED IN MAINTENANCE

Materials used in the maintenance of bituminous surfaces are the same as those used for construction. Occasionally short experimental sections of bituminous sand surfaces or bituminous mats are reconstructed by using special bituminous materials such as special cutback products, powdered asphalt, emulsions, and tars. The only place where a special method of reconstruction using an emulsion has been adopted is on bituminous sand surfaces. The method and material now used were adopted after trying several different methods and using several types of emulsion. The emulsion recommended is a very stable emulsion having an asphalt base of 30-60 penetration. The method of reconstruction used is to scarify a depth of about one and one-half inches for a width of nine feet and then apply the straight emulsion to the scarified material and mix immediately. The emulsion does not break for about two hours which gives sufficient time to secure thorough mixing. The mixed material is windrowed and more material scarified after which the emulsion is added and the process of mixing and windrowing continued until the top three inches of the surfaces for the full width has been mixed and windrowed. The mixed material is allowed to remain in the windrow for at least twenty-four hours before being aerated to remove moisture. The moisture content is reduced to 0.5 per cent or less before the bituminous sand is laid. An emulsion having a base asphalt of 30-60 penetration is used on the assumption that the original SC asphaltic oil will flux the hard asphalt in the emulsion and produce an asphaltic residue in the bituminous mixture similar to the residue resulting when an MC asphaltic oil is used.

Practically the same results may be obtained from the use of an RC cutback having a low penetration base asphalt. An advantage that is in favor of the use of emulsion is that it can be applied during wet weather, however, the moisture must be removed by aeration before the surface can be relaid.

Powdered asphalt has been tried for reconstruction of bituminous sand surfaces but has not proven satisfactory probably due to the quality of oil existing in the material to be reconstructed.

The present trend of maintenance in Nebraska is to pay more attention to the application of engineering principles on reconstruction and to use better field control. More attention is also being given to drainage, height of grade and reconstruction of shoulders which are one of the most vulnerable points of a bituminous surface.

TABLE I

TOTAL MILEAGE OF BITUMINOUS SURFACES AND THE APPROXIMATE MILEAGE GIVEN SPECIAL MAINTENANCE TO JANUARY 1, 1937.

	Total Mileage of Bituminous Surfaces					Approximate Mileage Receiving Special Maintenance by Years													
						Bituminous Mat Surfaces							Bituminous Sand Surfaces						
	Total Mileage Bit. Mat Surfaces	Bit. Sand Surfaces	Bit. Sand Mat Surfaces	Surface Treatment on 3″ Stabilized Base	Bit. Mats Constructed on Stabilized Base	Sealed or Light Armor Coated		Torn Up & Relaid Due to Subgrade Failure		Reconstructed Due to Mat Failure		New Stabilized Base Course Constructed	Sealed		Torn Up & Relaid Due to Subgrade Failure		Reconstructed Due to Surfacing Failure	
Year	1¼-3″ Depth	4-6″ Depth	3″ Depth	Base	Base	Const. Funds	Maint. Funds	Const. Funds	Maint. Funds	Const. Funds	Maint. Funds		Const. Funds	Maint. Funds	Const. Funds	Maint. Funds	Const. Funds	Maint. Funds
1928	5																	
1929	5	5																
1930	5	22																
1931	10	82																
1932	116	150							1									
1933**	151	157					30		1					7		2		12.0
1934	362	157					48		15	5	15			11		7		16.5
1935	449	168	21		15	93	31		8		3			32		9	6	5.5
1936	598	206	57	21	138	112	78	1	41	4	4			17		4		9
Total	598	206	57	21	153	205	187	1	66	9	22	4.0	—	67	—	22	6	43.0

Grand Total miles of bituminous surface including 1936 construction not completed............882

Summary of Total Mileage Given Special Maintenance

Total Bituminous Mat Sealed..................392 miles of a total of 598 miles
Total Bituminous Sand Sealed.................. 62 miles of a total of 263 miles
Total Bituminous Mat Torn Up and Relaid.................. 67 miles of a total of 598 miles
Total Bituminous Sand Torn Up and Relaid.................. 22 miles of a total of 263 miles
Total Bituminous Mat Reconstructed.................. 31 miles of a total of 598 miles
Total Bituminous Sand Reconstructed.................. 49 miles of a total of 263 miles

Grand Total Special Maintenance..................628 miles of a total of 882 miles
Grand Total Special Maintenance less Const. Sealing..........423 miles of a total of 882 miles

**Includes maintenance in previous years.

TABLE I-A

MILEAGE OF BITUMINOUS SURFACING CONSTRUCTED PRIOR TO 1936

RECEIVING SPECIAL MAINTENANCE IN 1936

Classified as to Type of Surface and Cause of Failure

Approximate Mileage Receiving Special Maintenance

	Bituminous Mat						Bituminous Sand					
	Sealed		Torn Up & Relaid Due to Subgrade Failure		Reconstructed Due to Mat Failure		Sealed		Torn Up & Relaid Due to Subgrade Failure		Reconstructed Due to Mat Failure	
Group No.	Const.	Maint.	Const.	Maint.	Const.	Maint.	Const.	Maint.	Const.	Maint.	Const.	Maint.
1							None					
2							None	1.55	None	1.70	None	5.1
3							None	13.42	None	1.21	None	None
4-5							None					
12							None					
6	None	30.89	None	20.63	None	None						
7	None	16.65	None	2.59	None	None						
8	None	5.05	None	3.04	None	None						
9	None	7.60	None	5.26	None	None						
10	72.0	None	1.0	None	3.84	0.25						
11	None											
13 Dist. 1	None	5.50	None	2.50	None	0.25						
2	None											
3	None											
4	None											
5	None	10.05	None	4.51	None	None						
6	None											
7	None	2.00	None	2.00	None	None	None	None	None	None	None	3.8
8	None	None	None	None	None	None	None	1.65	None	1.17	None	None
14 (1936)	40.0											
Total	112.0	77.74	1.0	40.53	3.84	3.75	None	16.62	None	4.08	None	8.9

In addition to the mileage shown above 4.0 miles of stabilized soil base course was constructed as a maintenance repair item.

TABLE II

NEBRASKA MAINTENANCE COSTS ON TYPICAL BITUMINOUS SAND SURFACES TO JANUARY 1, 1937

Group 1 Surfacing Constructed in 1931 Using Cutback Oil and Subgrade Sand

			Estimated Daily Traffic							Approximate Cost Per Mile per Year for Maint. of Surface				*Aver. Total Maint. Cost Per Mile Per Year	
											Special			Cost of Sealing	
Project	Patrol	Location	Cars	Trucks	Total	Plan Length in Miles	Per Mile	Approximate Original Cost Per Sq. Yd. per Inch of Plan Depth	No. Years Maint. Cost Recorded	Routine	Major	Sealing	Total	Included	Excluded
313A	825	O'Neill-South	58	82	240	9.49	5744	0.117	5.18	35	18	23a	76	320	297
80D	731	Weir	207	56	263	6.95	5027	0.119	5.00	18	87b	—	105	302	302
Group I Weighted Average for 16.44 miles								0.118		28	47	13	88	312	299

a. Includes cos tof sealing 3.25 miles on 18-foot width—0.3 gal. per sq. yd.
b. Includes 2 miles of construction of bituminous sand shoulders 2 feet wide.

*This covers all maintenance expenditures of every kind charged against the patrol as taken from Auditor's Statement.

TABLE III

NEBRASKA MAINTENANCE COSTS ON TYPICAL BITUMINOUS SAND SURFACES TO JANUARY 1, 1937

Group 2 Surfacing Constructed in 1931 Using Road Oil and Subgrade Sand

Project	Patrol	Location	Estimated Daily Traffic			Plan Length in Miles	Approximate Original Cost		No. Years Maint. Cost Recorded	Approximate Cost Per Mile per Year for Maint. of Surface				*Aver. Total Maint. Cost Per Mile Per Year	
											Special			Cost of Sealing	
			Cars	Trucks	Total		Per Mile	Per Sq. Yd. Per Inch of Plan Depth		Routine	Major	Sealing **	Total	Included	Excluded
80E	730	Mullen-West	207	56	263	6.90	5150	0.084	5.33	21	137a	—	158	290	
277F	718	Hyannis-Ashby	207	56	263	7.97	5150	0.084	5.00	15	198b	—	213	326	
681B&G	433	St. Paul-East	307	83	390	15.60	5050	0.082	5.00	64	212c	—	276	545	
233F&G	749	N. Platte-Tryon	75	21	96	11.70	4250	0.088	5.18	29	89d	—	118	232	
Group 2 Weighted Average for 42.17 miles								0.084		38	163	—	201	375	

a. Includes reconstruction of 1.0 miles and tearing up, relaying and sealing of 5.9 miles.
b. Includes reconstruction of 4.49 miles and tearing up, relaying and sealing of 3.48 miles.
c. Includes reconstruction of 10.8 miles and tearing up, relaying and sealing of 4.0 miles.
d. Includes partial reconstruction of 4.2 miles and sealing 1.4 miles.

*This covers all maintenance expenditures of every kind charged against the patrol as taken from Auditor's Statement.

**Sealing costs included in major maintenance.

TABLE IV

NEBRASKA MAINTENANCE COSTS ON TYPICAL BITUMINOUS SAND SURFACES TO JANUARY 1, 1937

Group 3 Surfacing Constructed in 1932 Using Road Oil, Subgrade Sand and Filler

Project	Patrol	Location	Estimated Daily Traffic			Plan Length in Miles	Approximate Original Cost		No. Years Maint. Cost Recorded	Approximate Cost Per Mile per Year for Maint. of Surface				*Aver. Total Maint. Cost Per Mile Per Year	
											Special			Cost of Sealing	
			Cars	Trucks	Total		Per Mile	Per Sq. Yd. Per Inch of Plan Depth		Routine	Major	Sealing	Total	Included	Excluded
3	419	Grand Island-West	535	130	655	4.30	4830	0.068	3.00	7	37	135a	179	319	184
202 I	871	Valentine-West	260	80	340	11.31	4650	0.066	4.42	10	12	5	27	166	161
317 C		Valentine-East	288	96	384	5.16	4750	0.067							
313 E	853	Bartlett-O'Neill	158	82	240	7.10	4600b	0.068	4.00	6	9	115a	130	268	153
631 D	319	Neligh-North	273	75	348	9.98	3900	0.058	4.00	17	4	16	37	169	153
639 D	829	Amelia	100	25	125	12.55	2850	0.090c	4.00	8	4	42	54	146	104
Group 3 Weighted Average for 50.40 miles								0.071		10	10	43	63	189	146

a. Includes sealing entire project 26-foot width.

b. Part State forces and part contract work.

c. Actual depth 4 in. rather than plan depth of 3 in., consequently cost per square yard per inch of actual depth would be approximately 0.067.

*This covers all maintenance expenditures of every kind charged against the patrol as taken from Auditor's Statement.

TABLE V

NEBRASKA MAINTENANCE COSTS ON TYPICAL BITUMINOUS SAND SURFACES TO JANUARY 1, 1937

Group 4 Surfacing Constructed in 1934 Using SC-3 Road Oil, Subgrade Sand and Filler

			Estimated Daily Traffic			Plan Length in Miles	Approximate Original Cost		No. Years Maint. Cost Recorded	Approximate Cost Per Mile per Year for Maint. of Surface				*Aver. Total Maint. Cost Per Mile Per Year	
											Special			Cost of Sealing	
Project	Patrol	Location	Cars	Trucks	Total		Per Mile	Per Sq. Yd. Per Inch of Plan Depth		Routine	Major	Sealing	Total	Included	Excluded
NRS-355A	854	Cumminsville-Elgin	87	66	153	5.04	6060a	0.090	2.17	10	—	—	10	106	106
NRH-233C	778	N. Platte-Tryon	75	21	96	5.21	4540	0.077	2.00	5	—	—	5	108	108
Group 4 Weighted Average for 10.25 miles								0.083		7	—	—	7	107	107

a. Very high filler cost.

*This covers all maintenance expenditures of every kind charged against the patrol as taken from Auditor's Statement.

TABLE VI

NEBRASKA MAINTENANCE COSTS ON TYPICAL BITUMINOUS SAND SURFACES TO JANUARY 1, 1937

Group 5 Surfacing Constructed in 1934 Using MC-2 Asphaltic Oil, Blow Sand Aggregate and Filler

			Estimated Daily Traffic			Plan Length in Miles	Approximate Original Cost		No. Years Maint. Cost Recorded	Approximate Cost Per Mile per Year for Maint. of Surface				*Aver. Total Maint. Cost Per Mile Per Year	
											Special			Cost of Sealing	
Project	Patrol	Location	Cars	Trucks	Total		Per Mile	Per Sq. Yd. Per Inch of Plan Depth		Routine	Major	Sealing	Total	Included	Excluded
80B	732	Hecla E. & W.	207	56	263	6.60	5440	0.156a	2.33	4	—	—	4	101	101
202A&D	815	Merriman-Leat	176	43	219	9.19	4340	0.130	2.08	65	—	—	65c	174	174
Group 5 Weighted Average for 15.79 miles								0.130		39	—	—	39	144	144

a. Over run in depth approximately 20 per cent. Approximate cost per sq. yd. per in. actual depth 0.128. Long filler haul. Completed in early summer.

b. No filler added. Selected sandy soil contained sufficient material passing No. 200 sieve. Completed in late fall.

c. Higher cost of surface maintenance on project 202 A&D attributed primarily to poor base, non-uniform laydown and insufficient aeration.

*This covers all maintenance expenditures of every kind charged against the patrol as taken from Auditor's Statement.

TABLE VII

NEBRASKA MAINTENANCE COSTS ON TYPICAL BITUMINUOS MATS

Group 6 Bituminous Mat Surfacing Constructed in 1932 Using Road Oil

Project	Patrol	Location	Estimated Daily Traffic			Plan Length in Miles	Approximate Original Cost		No. Years Maint. Cost Recorded	Approximate Cost Per Mile per Year for Maint. of Surface				*Aver. Total Maint. Cost Per Mile Per Year	
			Cars	Trucks	Total		Per Mile	Per Sq. Yd. Per Inch of Plan Depth		Routine	Special	Sealing	Total	Cost of Sealing	
											Major			Included	Excluded
124BCK	535	Chadron-East	360	90	450	14.04	2820	0.176	4.3	88	23	105	216	341	236
296A	715a	Ogallala-				11.89	2560	0.091	3.5	64	324	14	402e	677f	581
296B		Paxton	1380	220	1600	6.82	2250	0.128							
175A	116	Cheney-Bennet	475	92	567	5.87	2660	0.151	4.3	81	339	111	531g	826	715
147A&B	510	Kimball-East	960	240	1200	14.81	1690	0.096	4.0	67	113	—	180	299	
14A	826b	O'Neill-				1.29b	2830	0.168	3.3	42	286c	12	340	517	
158A		Atkinson	398	140	538	17.37b	2310	0.137							
46	623	Cambridge-													
254C		Indianola	420	250	670	13.69	1550	0.085	4.0	22	263d	21	306	473	
Group 6 Weighted Average for 85.70 miles								0.125		58	221	34	313	499	

a. Due to a slight relocation on Patrol 715 only 18.41 miles was actually maintained.

b. Due to adding a curve on Patrol 826 a distance of 18.88 miles was actually maintained. This figure used in computing maintenance costs per mile.

c. Includes cost of reconstructing 12 miles.

d. Does not include cost of reconstructing approximately one mile washed out in the Republican River flood of 1935.

e. Includes cost of reconstruction of 5.4 miles, tearing up and relaying 1.5 miles and sealing 9.0 miles.

f. Includes cost of construction of 1.5 miles stabilized soil base course and 1.3 miles bituminous stabilized base course. ($82 per mile per year.)

g. Includes cost of reconstruction of entire project.

*This covers all maintenance expenditures of every kind charged against the patrol as taken from Auditor's Statement.

TABLE VIII

NEBRASKA MAINTENANCE COSTS ON TYPICAL BITUMINUOS MATS

Group 7 Bituminous Mat Surfacing Constructed in 1933 Using Road Oil

Project	Patrol	Location	Estimated Daily Traffic			Plan Length in Miles	Approximate Original Cost		No. Years Maint. Cost Recorded	Approximate Cost Per Mile per Year for Maint. of Surface				*Aver. Total Maint. Cost Per Mile Per Year	
			Cars	Trucks	Total		Per Mile	Per Sq. Yd. Per Inch of Plan Depth		Routine	Special Major	Special Sealing	Total	Cost of Sealing Included	Cost of Sealing Excluded
E-260	504	Big Sprgs.-W	914	132	1046	5.28	1820	0.104	3.40	29	74	—	103	256	
E-149D NRH149E	508 508	Sidney-Brown. Brownson-Potter	780	78	858	10.22 11.26	1710 2000	0.106 0.107	3.25	69	271	4	344	461	
E-224D	725	Ogallala-Brule	914	132	1046	9.00	2140	0.112	3.30	47	258	46	351b	616c	492
NRH284B	707	Anselmo-Dunning	169	32	201	10.80	2660	0.165	3.00	45	28d	56	129	218	162
Group 7 Weighted Average for 45.56 miles								0.121		55	190	23	268	411	

a. Entire project sealed once and about 3 miles resealed. Approximately 8 miles torn up and relaid.

b. Includes cost of tearing up and relaying about 5 miles, reconstruction of 1 mile, sealing 9 miles and resealing 3 miles.

c. Includes cost of construction of 1.0 miles new stabilized soil base course. ($70 per mile per year.)

d. Two miles sealed.

*This covers all maintenance expenditures of every kind charged against the patrol as taken from Auditor's Statement.

TABLE IX

NEBRASKA MAINTENANCE COSTS ON TYPICAL BITUMINUOS MATS

Group 8 Bituminous Mat Surfacing Constructed in 1934 Using MC Asphaltic Oil

			Estimated Daily Traffic			Plan Length in Miles	Approximate Original Cost		No. Years Maint. Cost Recorded	Approximate Cost Per Mile per Year for Maint. of Surface				*Aver. Total Maint. Cost Per Mile Per Year Cost of Sealing	
											Special				
Project	Patrol	Location	Cars	Trucks	Total		Per Mile	Per Sq. Yd. Per Inch of Plan Depth		Routine	Major	Sealing	Total	Included	Excluded
282	564	Harrison-West	178	41	219	9.30	4030	0.191	2.33	23	—	78a	101	256	178
NRH265B	559	Crawford-Whitney	192	71	263	9.19	2880	0.136	2.25	64	15	114a	193	334	220
NRH & NRM317F	838	Ainsworth-Johnstown	300	40	340	9.92	4170	0.197	2.17	18	—	101	119	239	138
NRS332	323	Neligh-North	396	132	528	3.97	2450	0.125	2.33	86	48	204a	338	536	332
226	267	Milford-Seward	880	151	1031	6.70	3930	0.186	2.42	99	373	—b	472	643	518
NRH 79B	525	Minat.-Angora				6.64	3560	0.138c	2.25	60	13	120a	193	348	228
NRH 79D		Minat.-Angora	558	182	740	2.04	4370	0.138							
NRH236D		Bayard-North	572	202	774	3.67	4260	0.134							
NRH236A	521	Minatare-Angora	800	200	1000	9.12	3980	0.126	2.33	58	3	115a	176	263	138
		Group 8 Weighted Average for 60.55 miles					3730	0.158		54	49	101	204	346	236

a. Sealing paid from construction funds.
b. Sealing costs included in major maintenance.
c. Two different depths constructed.

*This covers all maintenance expenditures of every kind charged against the patrol as taken from Auditor's Statement.

TABLE X

NEBRASKA MAINTENANCE COSTS ON TYPICAL BITUMINUOS MATS

Group 9 Bituminous Mat Surfacing Constructed in 1934 Using SC-3 Asphaltic Oil

Project	Patrol	Location	Estimated Daily Traffic			Plan Length in Miles	Approximate Original Cost		No. Years Maint. Cost Recorded	Approximate Cost Per Mile per Year for Maint. of Surface				*Aver. Total Maint. Cost Per Mile Per Year — Cost of Sealing	
			Cars	Trucks	Total		Per Mile	Per Sq. Yd. Per Inch of Plan Depth		Routine	Special — Major	Special — Sealing	Total	Included	Excluded
NRH29	280	David City-Rising City	366	137	503	9.31	2740	0.130	2.25	46	21	—	67	231	231
76A 265M	548	Chadron-South	424	87	511	7.43 0.25	3560 5010	0.181 0.255	2.33	98	8	121a	227	388	267
NRH124A NRM108B	551	Hay Springs-West	500	75	575	5.99 0.75	3160 3040	0.150 0.144	2.25	22	—	148a	170	275	127
NRH158B	828	Stuart-Atkinson	382	86	468	10.49	2870	0.136	2.17	20	43	196a	259	402	206
257A 257B	193	Palmyra-Cheney	475	92	567	3.12 3.00	2740 2840	0.130 0.134	2.33	56	62	166	284b	452	286
NRH316A NRH316C	509	Bushnell-West	860	90	950	7.94 0.71	2040 1820	0.097 0.086	2.33	32	1	127a	160	286	159
Group 9 Weighted Average for 48.99 miles							2840	0.137		44	22	124	191	335	234
Group 9 Weighted Average for 39.68 miles (excluding Proj. 29)							2860	0.140		44	23	154	220	360	234

a. Sealing paid from construction funds.
b. Does not include cost of reconstruction which was paid from construction funds.

*This covers all maintenance expenditures of every kind charged against the patrol as taken from Auditor's Statement.

TABLE XI

NEBRASKA MAINTENANCE COSTS ON TYPICAL BITUMINUOS MATS

Group 10 Bituminous Mat Surfacing Constructed in 1935 Using MC Asphaltic Oil

Project	Patrol	Location	Estimated Daily Traffic			Plan Length in Miles	Approximate Original Cost of Mat		No. Years Maint. Cost Recorded	Approximate Cost Per Mile per Year for Maint. of Surface				*Aver. Total Maint. Cost Per Mile Per Year Cost of Sealing	
			Cars	Trucks	Total		Per Mile	Per Sq. Yd. Per Inch of Plan Depth		Routine	Special Major	Special Sealing**	Total	Included	Excluded
5	361	Norfolk-Mad.	592	127	719	7.03	3239	0.167	1.25	137	41	a	178	....	443
21	542	Alli.-Antioch	315	35	350	8.28	3726	0.132	1.25	46	—	481	527	652	171
79A & 301C	533	Bridgeport-Dalton	210	56	266	6.24	3382	0.120	1.25	15	—	323	338	416	93
†79F & 242C	525	Mina.-Alliance	363	100	463	4.54	3690	0.131	1.25	72b	3	421	496	628	207
87A & B	376	Norf.-Stanton	758	192	950	5.18	3407	0.176	1.33	21	105	417	593	770	363
133B & F	115	Palm.-Syrac.	226	44	270	14.74	2961	0.153	1.17	34d	—	489	523	688	199
140A &	705	Broken Bow-	363	102	465	7.07	4765	0.169	1.25	34	9	None	43	—	151
140K		Merna-				2.51	3818	0.197							
186ABC & 316B	575	Kimball-Bushnell	875	75	950	12.30	3319	0.118	1.25	20	—	302	322	477	175
211	119	Beatrice-So.	670	196	866	7.36	4186	0.149	1.25	19	22	368	409	523	162
224BCE	728	Brule-Chap.	924	132	1056	8.766	3828	0.136	1.25	22	12	368	402	590	222
317A	839	Johnstown-Woodlake	265	35	300	10.84	5200	0.185	1.25	7	46	None	53e	—	252
1⅜″ Mats Weighted Averages			419	95	514	29.46	3179	0.164		57	29	—	85e	—	282
2″ Mats Weighted Averages			532	87	619	65.40	4036	0.143		26	13	—	39e	—	184
All Mats (1935) Weighted Aver.			497	90	587	94.86	3770	0.150		35	18	—	53e	417	214
All Mats (1935) Armor Coated Weighted Averages						67.41	3489	0.139		30	12	399	441	593	194

a. Sealed but no cost data kept separately.
b. Includes $2 minor sealing.
c. Only about 2 miles sealed.
d. Includes $7 minor sealing.
e. Does not include sealing costs.

*This covers all maintenance expenditures of every kind charged against the patrol as taken from auditor's statement.

**Sealing paid from construction funds as part of construction.

†In combination with projects 79 B&D and 236D.

TABLE XII

NEBRASKA MAINTENANCE COSTS ON TYPICAL BITUMINUOS MATS

Group 11 Bituminous Mat Surfacing Constructed in 1935 Using SC-6 Asphaltic Oil and Powdered Asphalt

			Estimated Daily Traffic				Approximate Original Cost of Mat			Approximate Cost Per Mile per Year for Maint. of Surface				
											Special			
Project	Patrol	Location	Cars	Trucks	Total	Plan Length in Miles	Per Mile	Per Sq. Yd. Per Inch of Plan Depth	Recorded No. Years Maint. Cost	Routine	Major	Sealing	Total	Aver. Total Maint. Cost Per Mile Per Year
284C*	705	Mern-Anselmo	360	66	426	11.39	4547	0.162	1.25	34	9	—	43	151

*Maintenance costs in conjunction with Projects 140 A&K C. B. Bit. Mat.

TABLE XIII

NEBRASKA MAINTENANCE COSTS ON TYPICAL BITUMINOUS MATS

Group 12 Bituminous Sand Surfacing Constructed in 1935 Using MC-2 Asphaltic Oil

			Estimated Daily Traffic				Approximate Original Cost of Mat			Approximate Cost Per Mile per Year for Maint. of Surface				
											Special			
Project	Patrol	Location	Cars	Trucks	Total	Plan Length in Miles	Per Mile	Per Sq. Yd. Per Inch of Plan Depth	No. Years Maint. Cost Recorded	Routine	Major	Sealing	Total	Aver. Total Maint. Cost Per Mile Per Year
NRH111A	779	Ringgold-Tryon	35	17	52	4.431	7306	0.0958	1.00	18	—	—	18	160

TABLE XIV

SUMMARY OF AVERAGE MAINTENANCE COSTS FOR ALL TYPES OF BITUMINOUS SURFACES

				Approximate Orig. Cost			Approx. Cost Per Mile Per Year for Maint. of Surface					Aver. Total Maint. Cost Per Mile Per Year	
								Special					
Description of Bituminous Surface	Year	Data from Table No.	Miles Represented	Per Mile	Per Sq. Yd. Per In. of Plan Depth	Approx. No. of Yrs. Maint. Costs	Routine	Major	Sealing	Total	Total Excluding Sealing	Including Sealing	Excluding Sealing
1931 Bit. Sand Surfacing—C. B. Oil	1935	II	16.44	5440	0.118	4	31	59	16	106	89	355	339
1931 Bit. Sand Surfacing—C. B. Oil	1936	II	16.44	5440	0.118	5	28	47	13	88	75	312	299
1931 Bit. Sand Surf.—SC Oil	1935	III	42.17	4860	0.084	4	39	175	—	214	—	385	—
1931 Bit. Sand Surf.—SC Oil	1936	III	42.17	4860	0.084	5	38	163	—	201	—	375	—
1932 Bit. Sand Surf.—SC Oil & Filr.	1935	IV	50.40	4070	0.071	3	9	57	—	66	—	180	—
1932 Bit. Sand Surf.—SC Oil & Filr.	1936	IV	50.40	4070	0.071	4	10	10	43	63	20	189	146
1934 Bit. Sand Surf.—SC Oil & Filr.	1935	V	10.25	5290	0.083	1	11	0	—	11	—	133	—
1934 Bit. Sand Surf.—SC Oil & Filr.	1936	V	10.25	5290	0.083	2	7	—	—	7	—	107	107
1934 Bit. Sand Mat—MC Oil & Filr.	1935	VI	15.79	4800	0.130	1	46	0	—	46	—	148	—
1934 Bit. Sand Mat—MC Oil & Filr.	1936	VI	15.79	4800	0.130	2	39	—	—	39	—	144	144
1935 Bit. Sand Surf.—MC Oil & Fil'r	1936	XIII	4.43	7306	0.096	1	18	—	—	18	18	160	160
1932 Bit. Mat—SC Oil	1935	VII	85.78	2230	0.125	3	58	232	—	290	—	438	—
1932 Bit. Mat—SC Oil	1936	VII	85.70	2230	0.125	4	58	221	34	313	—	499	—
1933 Bit. Mat—SC Oil	1935	VIII	46.56	2100	0.121	2	46	253	—	299	—	422	—
1933 Bit. Mat—SC Oil	1936	VIII	46.56	2100	0.121	3	55	190	23	268	—	411	—
1934 Bit. Mat—SC Oil	1935	X	48.99	2840	0.137	1	41	221	—	262	—	384	—
1934 Bit. Mat—SC Oil	1936	X	39.68	2860	0.140	2	44	23	154	221	66	360	234
1935 Bit. Mat—SC Oil	1936	XII	11.39	4547	0.162	1	34	9	None	—	43	151	151
1934 Bit. Mat—MC Oil	1935	IX	53.85	3710	0.154	1	30	195	—	225	—	332	—
1934 Bit. Mat—MC Oil	1936	IX	60.55	3730	0.158	2	54	49	101	204	103	346	266
1935 Bit. Mat—MC Oil	1936	XI	67.41	3489	0.139	1	28	12	399	441	42	593	194
Weighted Average Expend. for Bit. Sand (1936)			139.48	4745	0.089	4	24	58	17	99	82	248	231
Weighted Average Expend. for Bit. Mat (1936)			311.29	2940	0.137	2.5	48	105	138	291	153	446	208
Weighted Average Expenditures for all Types of Bituminous Surfacing (1936)			450.77	3498	0.122	2.9	40	90	101	231	130	385	284

SUMMARY OF MAINTENANCE REPAIRS ON BITUMINOUS SURFACES

Patrol.. Location.. Year....................

Length of Patrol in miles...............Condition of Surface as of date reported..........................**

*Cause of Failure Subgrade Base or Mat	Date Work was Done	Location Station to Station	CLASS 1 ITEM 20 Major Repair to Bituminous Surfacing								CLASS 1 ITEM 21 Seal Coating Oil Roads			
			Torn Up & Re-laid Without the addition of new materials		Torn Up and Reconstructed Materials Added									
			Depth	Width	Type of Agg.	Tons Per Sta.	Type of Agg.	Tons Per Sta.	Type of Oil	Gal. Per Sta.	Type of Oil Used	Gal. Per Sq. Yd.	Type of Agg. Used	Lbs. Per Sq. Yard

NOTES: *See back of sheet. **See back of sheet.

REMARKS:

Submitted by: ....

Title ....

Date Submitted: ....

NOTES: Place the information concerning each type of repair on one line for each section or different location. Where stationing is not available, use calibrated mileage reckoned from the east or south end of the patrol.

*Under remarks, give explanation of type of failure which caused repairs to be necessary, making it clear whether the failure occurred due to subgrade, base or mat. It is important to report any unusual condition of the surface or subgrade. Use the back of the sheet if necessary.

**This rating is comparative only and may vary with the individual or time of the year the patrol is rated.

A indicates excellent condition with no major repair anticipated within the next year.
B indicates good condition with some major repair anticipated within the next year.
C indicates fair to poor condition with considerable major repair anticipated.
1 indicates excellent riding surface.
2 indicates fair to good riding surface.
3 indicates poor riding surface.

ADDITIONAL REMARKS:

Maintenance of Bituminous Surfaced Highways

By

RAY ROBINSON, Traffic Engineer,
North Dakota State Highway Department
Bismarck, North Dakota

At the present time North Dakota has five hundred miles of bituminous surfaced highways. Most of this five hundred miles consists of oil mat from two to three inches in thickness. A lighter mat has been used on several projects and has proven very satisfactory on a solid base and where the traffic is not too heavy. On practically all construction at the present time, SC-6 oil is used for the mat, MC oil for the tackcoat on the base before the mat is laid and RC oil for a sealcoat. We find that the mat from two to three inches thick is giving very good satisfaction with the exception of the Red River Valley where the soil is very dense and there is a very slow run-off. Special care is being taken in this section to see that a very substantial base is constructed before any mats are laid.

We are probably agreed on how to remedy faulty conditions of bituminous surfaces that are bound to occur from time to time regardless of how well the surfaces and bases have been constructed. Some of these conditions are failure of the base under the mats, wrinkling of the surfaces, cracking or alligator hide, ravelling of the edges and fractures of the surfaces. We know that these conditions can be remedied by patching, tearing up and re-laying, repairing and drying of the bases and sealing, I will, therefore, discuss briefly the maintenance organization, equipment, maintenance costs and accounting.

Patching and hand repairing work can be done by gang maintenance. Each crew should consist of from three to four men, including a competent Foreman. These crews should be equipped with a one and one-half ton truck, a tar kettle for heating the asphalt, a small storage tank and hand tools such as brooms, shovels and tampers. The premixed material used for patching should be placed in stock piles by another crew. This crew should have a small portable mixing and gravel crushing plant. Trucks can be hired by the cubic yard mile or ton mile at a very reasonable rate. With these trucks material can be hauled and placed in stock piles at convenient locations for the patching crews.

For tearing up and re-laying surfaces, a motor patrol with a scarifier and an oil mix moldboard and a five to seven ton road roller work to a good advantage. We have found that a road roller is very useful in pulverizing the old material after it has been torn up with a scarifier. Considerable experimenting has been done with disks of various types but none of these have proven very satisfactory due to the fact that it is very expensive to keep the disks sharp. Large storage tanks and oil distributors are also necessary for maintenance work.

Due to the large amount of expensive equipment required, we believe it economical to do as much maintenance as possible by contract where specifications can be written to cover the work. Sealing can be done by contract very economically if the job is of a suitable length.

With reference to maintenance costs and cost accounting, we are very much in favor of a uniform system for all State Highway Departments. In this way costs can be compared in various states. We would recommend the system that is now being worked upon by the American Association of State Highway Officials and may be adopted by many states in the near future. It is useless to quote figures on maintenance costs for comparative purposes at the present time. Each state has a different accounting system and certain items included in some are not included in others.

As the mileage of bituminous surfaced roads increases, the maintenance cost per mile will decrease considerably as the same amount of equipment is required to maintain a small mileage or a larger mileage.

In conclusion we would recommend for discussion in the maintenance division of your conference, first the possibility of writing specifications to cover as much maintenance work as possible, thereby eliminating an investment in expensive equipment. Second, that a uniform accounting system be adopted so that the maintenance costs in various states can be compared. This would make it possible to determine the best and most economical methods to use.

Maintenance of Bituminous Surfaces

By

T. R. PERRY, Bituminous Engineer,
Iowa State Highway Commission
Ames, Iowa

The successful maintenance of Bituminous Surfaces requires a well trained and economically directed field force. Cost keeping is necessary and should be of value if properly kept. A system of cost keeping that is valuable from an engineering standpoint as well as from the auditing side is desirable.

This paper will touch on the above two phases of Bituminous Maintenance, namely—

A. Bituminous Maintenance Instructions.

B. Cost Records.

BITUMINOUS MAINTENANCE INSTRUCTIONS

Maintenance Instructions can be of a general nature and thus avoid making definite recommendations so far as details are concerned. Instructions can also be prepared to cover detail operations which are of value to the field forces.

A happy combination of these two types of instructions we believe is desirable. These instructions should be based on keeping the bituminous surfaces in first class condition at all times. This service may cost considerable at times, however, the amount of money spent should not be considered a criterion on which to judge the quality of maintenance furnished. Generally speaking the actual results in the field are what count. In other words the maintenance expenditures on two roads might run $200.00 per mile for one road and $1000.00 per mile for the other. The fact that one road cost $800.00 more than the other road to maintain is not necessarily an indication that it was maintained any better than the other road.

A high yearly maintenance expenditure could mean that a higher type of construction is required to economically carry the traffic. It might also indicate that corrective steps should be taken to remedy certain weaknesses in the mat, or the base, or both. At any rate a high yearly maintenance expenditure calls for a careful study of all the items which might effect this expenditure including the maintenance organization itself.

The instructions should be prepared for a field organization that is interested in the work which is being done. The instructions should clearly set forth the results expected of the field force.

The Iowa State Highway Commission Maintenance Instructions C-58, which were sent out early this spring, are made a part of this paper. These instructions may not apply to other states but they do fit our conditions. It is not claimed that these instructions are complete or perfect in every respect but they will illustrate that a definite workable instruction to the field forces is necessary.

These instructions are revised from time to time as conditions warrant. They are prepared in loose leaf form so that changes can be easily made, and are a part of the General Maintenance Instructions.

The maintenance and the construction of bituminous surfaced roads in Iowa is handled by the Maintenance Department under direct supervision of the Bituminous Engineer.

It is hoped that the following instructions may contain some items that can be made applicable to the maintenance work in other states.

MAINTENANCE INSTRUCTIONS, C-58
MARCH 22, 1937

MAINTENANCE OF BITUMINOUS SURFACED ROADS

This letter supersedes and replaces Maintenance Instructions, B-66 and letter to Division Maintenance Engineer dated July 21, 1936.

The construction and maintenance of Bituminous Surfaced roads has developed rapidly during the last two or three years. As a result some practical methods for both construction and maintenance have been produced based on experience in the field and in the laboratory.

New equipment has also been developed which has simplified and speeded up some of the old slow and cumbersome methods used in the past.

The types of bituminous surfacing built to date might be classified as follows:

(A) Light Surface Treatments, for dust alleviation.
(B) Mats.
(C) Heavy Surface Treatments.

In some cases the bituminous surfacing has been built on a substantial base, in other cases on the existing road surface without any additional support. Future bituminous surfacing will be built only on substantial bases. However, regardless of how the surfacing was constructed it is the duty of the Maintenance Department to keep these roads in good shape and intensive maintenance is required for the old surfaces as well as the newer sections.

(A) **Light Surface Treatment,** for dust alleviation is a type of construction used in only three places in Iowa, namely Road No. 64 in Jackson County east of Maquoketa, Road No. 1 and 38, Cedar County from Tipton to West Branch and Road No. 60 on the Wright-Humboldt County line from Renwick south to Goldfield. These surfaces require in general a retreatment each year consisting of ¼ gallon of bitumen and 25 pounds of aggregate per square yard. The surface should be well sealed before winter sets in. If the surface becomes badly disintegrated or distorated during the winter or early spring it should be maintained as an untreated gravel surface until retreated.

Pot holes of sufficient size to cause discomfort or to be dangerous to the traveling public should be filled promptly with premixed bituminous material or well graded aggregate mixed with soil binder.

(B) **Mat Surfaces** vary from one inch to three inches in thickness. Very few of these surfaces are on a supported base and breakups are frequent in the spring. Most of the patching should be done with premixed material. Spots which crack or "alligator" shall be sealed as soon as possible to keep out surface moisture. We have more rolls and corrugations on mats than on the other types of construction. The surface should be kept as smooth as possible. Light surface discings will help to smooth up a rough surface. Disc only deep enough to cut to the bottom of the low place.

Mats may have to be sealed from time to time in order to withstand traffic. The seal may be with or without cover aggregate. This operation should be handled by the State Crew and not by the Local Crew.

(C) **Heavy Surface Treatment** is the common type of construction in Iowa. Suppose we take a road just finished by the contractor and turned over to the maintenance department to maintain say on August 1st. The maintenance procedure is as follows:

Keep the loose aggregate uniformly distributed over the road and roll continuously for at least a week. In general, all material will have been incorporated in the surface by this time. In case all material is incorporated in the mat there will be no need for the intensive rolling and sweeping. At the end of this time any surplus aggregate should be swept to the shoulder and there held in reserve to take care of any bleeding that may occur on the surface. When bleeding stops any excess material should be salvaged if there is sufficient material to justify the expense. A rough guide to use in determining when the mat has taken up all the aggregate that it will is to use a pick or some blunt instrument and shove longitudinally along the surface. If the mat shoves and pushes it will take more aggregate, if it does not it is safe to remove the surplus aggregate.

There will probably be surplus aggregate left when MC or RC bitumen has been used. SC bitumen will probably require additional aggregate. Do not apply additional aggregate at the rate of more than 5 pounds per square yard at one time and the spread should be confined to the center 12 feet of roadway. Traffic will naturally throw the aggregate to the outside. Use material spreaders to spread the aggregate. Hand spreading will make an uneven surface.

Assume that it is October before the above work is completed. Now start to prepare for winter. See that any breaks in the surface are taken care of, that the road is in first class shape for winter. Keep the cracks filled during the early winter and early spring.

When spring comes keep the surface tight so the water will not get to the base, all holes patched and the shoulders smoothed. Supply extra aggregate as needed when hot weather comes. Do not over blot.

There are a number of fundamental principles common to all three classes that might well be covered as follows:

1. **Organization.** The Maintenance of Bituminous Surfaces required the **close attention** of the Division Maintenance Engineer. In each county having bituminous surfaces a few men should be trained to do this class of maintenance. Pick out men who are up on their toes and you will make progress.

Remember the old saying a stitch in time saves nine. Train yourself and your men to watch these surfaces and keep them in A-No.-1 shape all the time. If someone else has to come in and tell you what to do and when to do it your maintenance is going to cost more than it should. Keep those in charge of bituminous surfaced roads **bituminous minded.**

2. **Centerline Marking.** Only in exceptional cases will a centerline be marked on bituminous surfaces as such marking has a tendency to spread the traffic lanes to the outer edges of the surface and to the unsurfaced shoulders to some extent.

These exceptional cases will be due to unusual alignment and the centerline should not be marked unless authorized by the District and Central office. Paint for this marking will be ordered by the Central office and definite instructions issued relative to applying the paint.

3. **Shoulder Maintenance.** The shoulders should be kept smooth at all times so that the surface water will quickly drain away. At least one application of primer bitumen has been applied and an effort should be made to preserve this bitumen in your maintenance work. Frequent rolling will keep the shoulders well compacted and is the best safeguard against rutting, or other distortions of the surface and will do much to preserve the primer bitumen. However, rolling should not be carried on if the surface shoves or curls up. The roller should not be operated faster than four or five miles per hour.

4. **Repair of Holes due to Settlement.** Sometimes settlements of subgrade occur which cause holes or depressions in the surface. Such holes should be repaired by cutting out all bituminous surfacing, backfilling the subgrade to the planned subgrade elevation, being sure that this material is well tamped. The subgrade should then be primed and allowed to dry thoroughly, then a surface similar to the original construction should be made.

5. **Repair of Rolls or Corrugations.** These are usually caused either by moisture between the prime and the surfacing material or else by an excess amount of bitumen in the aggregate. The best cure in case of moisture is to take up the surface, dry out the material and then relay it. Should the mixture be lean after drying add additional bitumen mix thoroughly and relay. Exercise care and not add too much bitumen.

A surface containing excess bitumen should be taken up, remixed with additional aggregate and relaid. Sometimes additional aggregate can be rolled into the surface and thus make a stable mixture. Determine carefully whether it is moisture or excess bitumen before starting the corrective treatment.

6. **Repair of the Base.** On stabilized bases where the stabilized material has been spread from shoulder to shoulder, any ravelling or disintegration should be immediately repaired. The repair can be made by replacing the loosened base with premixed bituminous material or by a well mixed graded aggregate and soil binder. The latter is much cheaper in case the repair is extensive.

When the stabilized base has been spread 24′ wide extreme care should be taken not to allow surface moisture to penetrate the edge of the base and soften the base material. Keep the edges sealed up tight.

7. **Premixed Material.** Sufficient aggregate and bitumen should be available at all times to be used as needed. It is much better to mix up this material as needed than to have a supply which has been mixed up for several months. The new bitumen mixers have solved the mixing problem.

When mixing up the aggregate and bitumen keep these two cardinal points in mind.

(a) The aggregate must be dry. Wet aggregate will ruin the mixture.

(b) Be sure that the correct amount of bitumen is added.

8. **Shrinkage Cracks.** Shrinkage cracks are more numerous some years than others. These cracks may run transversely or longitudinally across the surface and usually start to develop about December. They may continue to develop until February or early March. The cracks will vary from small checks to large cracks one-half inch in width or more.

These cracks should be kept filled to prevent surface water from entering and softening the base. The cracks can be filled with sand and then hot bitumen applied or the regular paving crack filler can be used. The paving crack filler is more expensive.

9. **Economical Patching.** Each spring that a bad breakup occurs the question arises, shall this surface be patched or shall we wait until the ground and weather settles and then make a permanent job? Good judgment is required to make this decision. Our own conclusions in general are that many breakups can be avoided if the surface is kept water tight. Further that early patching generally saves money in the long run. However, if there appears no doubt but what the entire surface or certain sections of the surface will have to be torn up later and reworked then the surface should be bladed off the roadway to the shoulder and the subgrade allowed to dry out. Particularly is this true when frost boil treatments or other extensive base treatments are to be made.

10. **Surface Patches.** Surface patching is divided into two classes.

(a) Penetration Patch.
(b) Premixed Patch.

The penetration patch consists of applying an application of bitumen and then covering with ten pounds of aggregate per .1 gallon of bitumen per square yard of surface. The aggregate should then be thoroughly imbedded in the bitumen by rolling or tamping. A second application can be made if required. The surface should be swept clean before the first treatment is made. Also all loose material should be swept off before the second treatment is applied. This type of patching should not be made if the depth to be patched is one inch or more in depth.

The premixed patch type of patching consists of removing the loose surfacing, squaring up the hole, prime the bottom of the hole and the sides with a light prime. Be sure the hole is thoroughly broomed or cleaned out before the prime is applied. If you do not have any prime bitumen take whatever bitumen you have and cut it back with about 25 per cent fuel oil. **Do not mix these two when hot.** Care should be taken not to use too much prime so that the patch will become fatty. When the prime has dried **thoroughly** fill the hole with **premixed material.** This material should be compacted by tamping or rolling so that the surface will be left level with the surrounding road. Do not string this type of patching out anymore than necessary. This method of patching is preferable for holes where the depth is one inch or more. Reuse the old surfacing material whenever possible. Do not throw it way.

10. **Heating.** Bituminous material shall be heated to a temperature which will permit uniform spreading, but under ordinary conditions within the following limits for the respective materials:

Designation	Temperature	Designation	Temperature
SC-1	100-120	MC-3	140-180
SC-2	100-130	MC-4	170-210
MC-1	80-100	MC-5	200-235
MC-2	100-140	TC-3	130-150
TC-1	90-125	TC-4	170-200
TC-2	120-140	RC-3	120-140
		RC-4	170-200
SC-3	130-160		
SC-4	170-200	RC-0	80- 90
SC-5	130-160	RC-1	90-100
SC-6	170-200	RC-2	100-110
SC-7	190-235		
SC-8	210-250		
SC-9	300-350		

Before undertaking a remixing job or before trying out new maintenance methods on a large scale the central office of the Maintenance Department should be consulted.

W. H. ROOT,
Maintenance Engineer.

COST RECORDS

The desirability of keeping maintenance costs on a uniform basis has been strongly in evidence during recent years. Attempts have been made by various highway groups to devise such a system. However, it is not easy to change from one system of cost keeping to another but in spite of this difficulty real progress has been made.

The system used in Iowa follows out the recommendations of the Mississippi Valley Association of State Highway Officials and the American Association of State Highway Officials together with our own state auditing requirements.

All maintenance charges are made against various units. These units are designated as follows:

Unit 1. Concrete Pavement
Unit 2. Gravel Surfcae
Unit 3. Earth Surface
Unit 4. Bituminous Surface
Unit 5. Brick Pavement

So far as this paper is concerned all bituminous charges are made against Unit 4.

The system of cost keeping to be outlined in this paper is furnished to illustrate the dual value desirable and not offered as a model for use in other states. Briefly, the various steps necessary in classifications and the essential forms and instructions preliminary thereto are included.

All bills or payrolls are prepared on attached Forms 503 and 504. Maintenance Instructions C-29 cover the various classifications of expenditures.

Pages 532 and 533 show the summary of the Iowa 1936 Bituminous Maintenance expenditures.

Form 520, pages 535, 536 and 537, illustrate the items of maintenance included under each heading shown on pages 532-533.

It will be noted that items which should really be paid from construction funds are actually built and paid for from maintenance funds are classified as Betterments. All other maintenance expenditures are classified as Maintenance Proper.

Pages 538 to 543, inclusive, illustrate a typical record that is kept for each bituminous surfaced road in the state. The data shown in this record is prepared at the close of the fiscal year by the Division Maintenance Engineer. (Each Division Maintenance Engineer in Iowa has charge of the maintenance operations in this division which comprises three to four counties). This part of the cost keeping record is of value from an engineering standpoint and as a ready reference for information needed on inspection trips and in preparing recommendations and estimates for future maintenance work.

This particular section of road as shown by pages 538 to 543 was included as a part of this paper because it illustrates the nature of the various types of maintenance work which have been required on this road.

MAINTENANCE INSTRUCTION, C-29

NOVEMBER 26, 1934

CLASSIFICATION OF EXPENDITURES

The following classification of expenditures will supersede and replace Maintenance Instructions, B-16 (Revised), dated March 25, 1932.

Our maintenance expenditures are classified two ways; first, as to the part of the road upon which the work is done; and, second, as to the kind of material purchased. These classifications are shown on the back of the voucher form, 504.

The first classification, from an engineering standpoint, is the important one. This is the classification which the patrolman is called upon to make on his time sheet. Instructions to Patrolmen, Form 520, should be retained from Instructions, B-16. This form will assist the patrolmen in making their classifications. We want to call the attention of the Division Maintenance Engineers to the fact that it is always necessary for them to check and revise the distribution made by the patrolmen. There are one or two points which we want you to watch in particular. Work on pavement shoulders should be classed under ''Road bed,'' not under ''Surface maintenance.'' Equipment purchases and repairs should be charged against the classification upon which the equipment is to be worked. A little care should be used in making this distribution.

The second classification on the voucher is of particular interest to the general public. The following notes may be of assistance in classifying some of the expenditures.

SUPERINTENDENCE

Superintendence should include the salaries, expenses (including office rent and supplies) and transportation of the Division Maintenance Engineer and his stenographer. No other charges whatever should be included.

LABOR

Patrol

This item covers all regularly employed maintenance labor.

Extra

This includes all extra labor hired for a few days at time occasionally.

All labor paid direct by payrolls must be included under either ''Patrol'' or ''Extra.'' It should in no case be classified against ''Real estate and buildings,'' ''Equipment'' or any other items in this classification.

EQUIPMENT

New

This includes all road maintenance equipment, also shop equipment as follows:

Shop tools
Lathes
Grinders
Paint guns
Forges
Grease guns
Oil cans
Drill presses
Fire extinguishers

Repairs and Blades

This includes repair parts for all equipment items originally charged under new equipment, blades for equipment and garage items as follows:

Coal
Electricity
Water
Garage telephone

RENTAL

Equipment and Real Estate

This item includes all rentals paid except for office and telephones.

MATERIALS

Paint

This item includes all paint purchased, including sign and centerline paint.

Culvert Pipe

This includes all culvert pipe purchased, such as concrete, vitrified clay and corrugated steel or iron.

Tar, Asphalt and Road Oil

This includes all purchases of these materials no matter where used.

Gas, Oil, Grease and Alcohol

This includes in addition to the items listed glycerine or other anti-freeze materials.

Snow Fence and Posts

This includes the total cost of these items, including freight.

Road Signs and Posts

This, also, includes sign bolts and brackets.

Lumber, Piling and Guard Rail Posts

This is self-evident. It includes the total cost of these items no matter where they are used, and includes the freight.

Gravel, Crushed Rock and Shale

This includes all expenditures for these items regardless of whether they are used for surfacing or for other purposes. It, also, includes sand and where the materials are shipped it includes freight to destination.

Miscellaneous Materials

This includes all materials not provided for in previous classifications.

REAL ESTATE AND BUILDINGS

New

This includes in addition to the expenditure for purchase of

STATEMENT SHOWING BITUMINOUS EXPENDITURES FOR MAINTENANCE PROPER AND BETTERMENTS BY COUNTIES ON THE PRIMARY ROAD SYSTEM, December 1, 1935 to November 30, 1936, AS TAKEN FROM CHAPTER II, SCHEDULE NO. 1-M, 1936 IOWA STATE HIGHWAY COMMISSION ANNUAL REPORT.

County	Ave. Daily Traffic Count	Mileage	Maintenance Proper				Betterments			Tot. Maint. Proper & Betterments
			Surface	Road Bed	Structures	Snow Removal	Surface	Road Bed	Structures	
Adair	550	10.3	6,438.94	1,185.03	358.54	1,338.66				9,321.17
Adams	700	15.1	14,368.11	621.83	339.81	946.74	1,192.05			17,468.54
Allamakee	400	10.6	No Bituminous Maintenance Expediture made in 1936. Construction finished late in fall							
Appanoose	800	5.7	6,583.33	1,030.23	333.06	598.69			29.13	8,574.44
Audubon	450	2.0	949.01	196.56	120.13	194.41				1,460.11
Benton	375	10.0	8,092.49	460.01	147.44	509.76	5,326.97	−161.00		14,375.67
Boone	400	11.1	3,718.33	340.41	111.74	1,329.28				5,499.76
Bremer	500	1.0	621.57	33.87	54.30	213.81			17.35	940.90
Butler	450	10.5	2,256.88	409.84	201.97	1,316.65				4,185.34
Carroll	400	10.8	771.19	121.88	82.99	477.72				1,453.78
Cass	425	34.2	18,247.35	2,678.01	1,254.64	3,150.32				25,330.32
Cedar	450	18.1	12,743.58	1,415.63	6,873.03	1,842.26				22,847.50
*Cerro Gordo	250	3.9	427.89	161.06	118.28	553.58			44.60	1,305.41
Clarke	400	2.9	339.46	69.17	71.84	97.03				577.50
*Dickinson	200	7.8	886.10	207.18	4.06	33.75			84.85	1,215.94
Fayette	400	13.3	3,814.76	491.64	547.60	1,290.13		232.91		6,377.04
Fremont	500	24.1	8,399.64	1,303.45	699.75	1,752.72	−334.10			11,821.46
Greene	370	3.9	84.65	2.00	7.00	44.33				137.98
Grundy	400	7.0	2,554.22	338.95	100.95	918.28		140.83		4,053.23
Guthrie	500	12.0	527.96	358.99	74.14	336.23	−367.56	90.60		1,020.36
Hamilton	650	18.1	4,945.33	468.44	337.94	1,284.88		1,188.45		8,225.04
Hancock	400	7.3	722.71	129.35	36.74	279.69				1,168.49
Harrison	250	9.0	4,472.62	105.03	82.21	55.37	130.98			4,846.21
Humboldt	400	5.5	4,836.08	235.74	42.35	487.35	492.72	51.00	25.35	6,170.59
Iowa	400	12.8	788.68	400.37	78.82	211.85				1,479.72
Jackson	400	28.2	18,666.08	4,885.46	1,136.19	4,571.71	12,227.80	6.80	56.43	41,550.47
Johnson	600	7.9	992.52	2,227.44	263.48	1,816.31				5,299.75
Kossuth	400	8.1	3,981.52	425.70	126.11	1,086.09	1,395.34	1.95		6,998.71
Lee	760	9.1	7,663.93	2,228.39	1,514.60	614.42	5,641.09	1.29		17,663.72
Lucas	500	11.0	9,874.19	1,441.86	270.56	874.48	1,050.30		1.35	13,512.74
Marion	450	15.0	7,491.38	2,154.06	538.92	1,109.94			502.07	11,796.37
Marshall	350	.7	269.38	5.15	1.41					275.94
Mitchell	230	8.1	1,548.31	233.56	181.68	1,055.17	14.84			3,033.56
Monroe	300	2.0	3,134.97	171.44	55.81	316.35			110.71	3,789.28
Montgomery	450	17.2	3,691.97	2,029.24	851.14	1,530.60				8,102.95
Page	750	2.0	-5,539.07	755.50	-131.68	-1,523.62	1,572.50			−4,866.37

Plymouth	375	27.9	11,715.55	1,817.49	820.90	4,172.21	47,201.08	9,776.34		75,503.57
Polk	300	4.0	1,182.53	260.27	45.89	463.89			14.00	1,966.58
Pottawattamie	450	25.9	10,161.02	638.32	410.08	1,726.39	724.66			13,660.47
Scott	950	.8	36.10	42.45	41.53	43.19				163.27
Shelby	450	5.2	-201.65	301.40	17.40					117.15
Tama	250	8.3	826.21	50.00	44.64	523.43	1,471.75	161.00		3,077.03
Taylor	600	24.5	21,435.48	2,652.40	914.47	2,974.09	20,160.36			48,136.80
Warren	600	12.8	10,870.50	1,580.46	134.33	1,166.45	288.32	–113.16		13,926.90
Winneshiek	350	7.8	2,700.76	426.59	451.77	1,680.62		140.80		5,400.54
Wright	400	5.5	4,639.80	402.71	38.14	728.69	592.07	–30.50	12.15	6,383.06
		499.0	222,732.36	37,494.56	19,806.70	44,193.90	98,781.17	11,487.31	897.99	435,375.71
Avg. Cost		488.4	456.04	76.77	40.55	90.48	202.25	23.52	1.84	891.43

*–Resort road and summer traffic would be much heavier.

Traffic counts were taken during the winter of 1934 and 1935 and are dated as of March 1935.

Traffic counts including summer traffic are not yet available.

land (including gravel pits) and building construction the following items which really become a part of the property:

- Gas pumps and tanks
- Wiring
- Lighting fixtures
- Fences
- Grading of yard
- Surfacing of yard and drives
- Trolley and hoist
- Bolt racks and cabinets
- Furnaces
- Oil racks
- Benches
- Unloading platforms
- Plumbing
- Wells
- Paint booths and exhaust fans
- Side walks
- Pavement assessments
- Sewer assessments

Repairs

This includes repair on any of the items originally classified under "Real estate and buildings—New."

CONTRACTS INVOLVING LABOR

This includes the total of all contracts involving labor. We will not attempt to split these contracts between labor and materials; for instance, a gravelling contract totalling $5,000 which is based upon gravel delivered on the road at $2 per yard will be classed under this heading as $5,000 even though we might be able to figure that $3,000 of the contract actually covered the cost of the gravel f.o.b. railroad station.

W. H. Root,
Maintenance Engineer.

INSTRUCTION TO PATROLMEN

CLASSIFICATION OF WORK FOR TIME BOOKS

FORM 520

All maintenance work is divided into two main classes: maintenance proper and betterments. Practically all patrol work falls in the maintenance proper class and this of course is the class of work in which you are interested. Betterment work should never be undertaken by the patrolman except under specific instructions from the Division Maintenance Engineer. We are showing below the various classifications of maintenance work and under each classification have listed the principal items of work which you will have occasion to classify in your time books.

MAINTENANCE PROPER

A. Surface

1. Dragging
2. Blading or scarifying surface
3. Maintenance graveling
4. Patching or retreating oiled roads
5. Mudhole bridges
6. Filling pavement cracks
7. Raising pavement slab
8. Repairing blow-ups in pavement
9. Real estate and buildings for housing surface maintenance equipment and materials
10. Original cost and repair of equipment used on surface maintenance

B. Road Bed

1. Blading ditches
2. Slip work in ditches or on shoulders
3. Weed cutting and destruction of noxious weeds
4. Clearing right-of-way
5. Seeding slopes
6. Filling ruts along pavement with earth, gravel or rock
7. Real estate and buildings for housing roadbed maintenance equipment and materials
8. Original cost and repair of equipment used on roadbed maintenance
9. Cleaning mud off pavement
10. Repairing surfaced shoulders
11. Right-of-way markers

C. Structures

1. Repairing or painting guard rail
2. Repairing or painting bridges and culverts
3. Repairing or painting road signs
4. Repairing baffles
5. Repairing tile

D. Snow Removal

1. Erecting and removing snow fence
2. Blading or plowing snow from the road surface
3. Placing of sand or cinders on icy surfaces

BETTERMENTS

A. Surface

1. Graveling a dirt road

B. Road Bed

1. Raising or widening grades
2. Rounding corners
3. Minor relocations
4. Right-of-Way for above items
5. Surfacing shoulders
6. Construction of curb along paving

C. Structures

1. New guard rail
2. New baffles
3. New bridges or culverts, including channel changes
4. New tile
5. Extensive work on bridges which raises the bridge to a higher class
6. Replacing wood stringers with steel
7. Replacing wood floors with concrete
8. Replacing wood or steel piers with concrete
9. Mat coats, asphalt plank or traffic treads on bridge floors

> Be sure to show in your time book each day the kind of work done; also, before turning your time book into the Division Maintenance Engineer be sure to sign it on the last page.

PATROLMAN'S DUTIES

You are hired by the State to maintain a certain section of road. In such capacity you are the direct representative of the State Highway Commission and you should conduct yourself accordingly. Be courteous to the public at all times. Cooperate with your fellow employees. Follow explicitly the instructions from your Division Maintenance Engineer. Do not take orders from or pay out any cash to strangers who claim to be representatives of the State. Always be loyal to your employers.

It is your duty to be on the road whenever road and weather conditions are such that you can improve road conditions. Your duties on the road are:

1. **Keep your patrol section passable.** If for any reason it becomes blocked and you alone cannot open it, notify the Division Maintenance Engineer at once.

2. **Keep your section smooth.** Do not make excuses if your roads are rough but get out and get busy.

3. **Keep your signs clean and straight.** If any are broken see that they are replaced promptly.

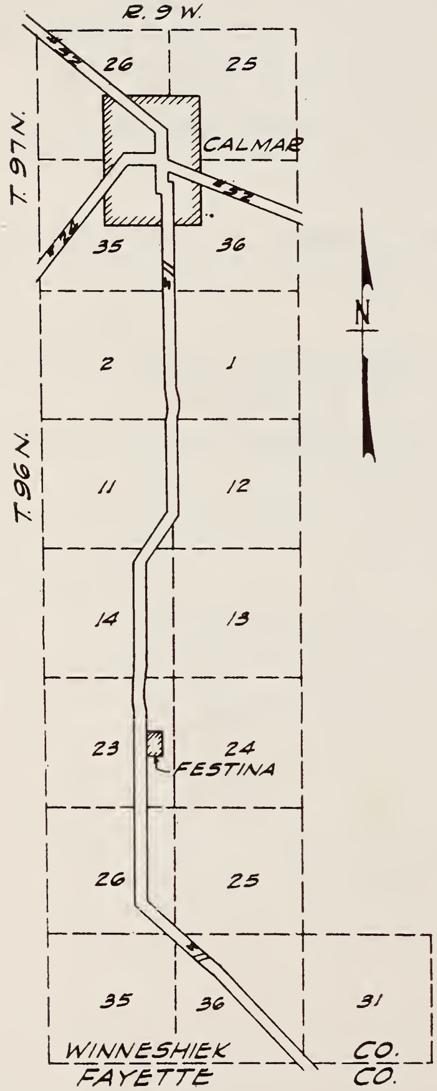
4. **Keep the right-of-way clean.** Cut the brush and weeds and do not let any junk accumulate.

5. **Keep pavement shoulders filled and smooth.**

6. **Keep waterways at bridges and culverts open.**

7. **Safeguard the traveling public at all times.**

WINNESHIEK COUNTY
BITUMINOUS SURFACING PROJECT P-177
PRIMARY ROAD #11 - 7.4 MILES
1932 CONSTRUCTION.



WINNESHIEK COUNTY
IOWA NO. 11 PROJ. 177
BITUMINOUS SURFACING

WINNESHIEK COUNTY

Primary Road No. 11—Project P-177
Bituminous Surfacing Project
1933 Construction

Sec. (A11) Fayette County line to Calmar—7.4 Miles

DESCRIPTION OF WORK

(a) By Maint. Dept.—Special subgrade treatment prior to priming and the redistribution of aggregate in windrow to obtain uniform cross-section.

(b) By Contract—Bituminous mat on existing base. RO-1 primer applied .4 gal. per sq. yd. 24′ wide. RO-2 binder oil applied 16.4 gal. per cu. yd. Mat laid 22′ wide.

COST DATA

(a) Base Cost (900′)

(1) By Maint. Dept.	
Special subgrade treatment.	
Labor and rentals	$ 642.71
(2) By Contract—M. O. Weaver (Final Estimate)	
Sand in place for subgrade treatment, 340.2 cu. yds. @ .75	255.15
Rock ballast in place 578.0 cu. yds. @ $1.25	722.50
Total Cost of Base	$ 1,620.36
Average Cost per Mile	$ 9,506.11

(b) Surface Cost

(1) By Maint. Dept.—Redistribution of aggregate in windrow.	
Labor and rentals	$ 104.20
(2) By Contract—M. O. Weaver (Final Estimate)	
Class "A" Aggregate 3996.8 cu. yds. @ $1.17	$ 4,676.26
A. R. Hewitt (Final Estimate)	
Additional Class "D" Aggregate 450 cu. yds. @ $1.20	540.00
Cost of material in pit 450 cu. yds. @ .10	45.00
Gaus-Culligan (Final Estimate)	
Heating, hauling & applying bituminous material, 124,024 gal. @ .015	1,860.36
Manipulation of Mixture 7.4 Mi.	2,721.30
Standard Oil Co. (Final Estimate)	
RO-1 Primer Oil 49,464 gal. @ .0312	1,548.95
RO-2 Binder Oil 69,361 gal. @ .0312	2,164.05
Total Cost of Surface	$13,660.12
Average Cost per Mile	$ 1,845.96

WINNESHIEK COUNTY

Primary Road No. 11—Project P-177
Bituminous Surfacing Project
1933 Construction

Sec. (A11) Fayette County line to Calmar—7.4 Miles

DESCRIPTION OF WORK

(a) Maintenance Dept.—None.

(b) Contract—Priming shoulders and applying oil to stockpile material.

COST DATA

(a) Base Cost
  (1) By Maint. Dept.—None.
(b) Surface Cost
  (1) By Maint. Dept.—None.
  (2) By Contract
  Gaus-Culligan (Final Estimate)

Road Oil Binder—furnished and apply RO-2 Binder Oil 25,652 Gals. @ .0546	$1,400.60
A. R. Hewitt—Class "D" Aggregate—delivered on road 251.77 Cu. Yds. Class "D" @ 1.80	453.19
Total Cost of Surface	$1,853.79
Average Cost per Mile	$ 250.51

ACCUMULATED CONSTRUCTION COSTS

Sec.—Fayette County line to Calmar

(1) Base	
1932	$ 1,620.36
1933	
Total Cost to Jan. 1, 1936	$ 1,620.36
(2) Surface	
1932	$13,660.12
1933	1,853.79
Total Cost to Jan. 1, 1936	$15,513.91
Total Average Cost per Mile	$ 2,315.44

ANNUAL RECORD OF MAINTENANCE OPERATIONS

For Bituminous Surfacing Projects
From January 1, 1935, to December 31, 1935

County, Winneshiek; Road No. 11; Miles, 7.8; Const. Proj. P-177

A. Base
  (1) Description of Work:—Frost Boil Treatment.
  (2) Cost of Work:

a. Labor: 2331½ Hrs. @ .50	$1,165.75
1076 Hrs. @ .40	430.40
138 Hrs. @ .60	82.80
471 Hrs. @ .45	211.95
2 Hrs. @ .61	1.22
408½ Hrs. @ .65	265.52
6 Wks. @ 31.20	187.20
	$2,344.84
b. Materials: 427½ Cu. Yds. Sand @ .10	$ 42.75
800 Cu. Yds. Gravel @ .95	760.00
Dynamite, caps, etc.	135.75
390 Ft. Sewer Tile @ .225	87.75

406 Ft. Sewer Tile @ .08	32.48
16½ Tons Lime Dust @ .40	6.60
	$1,065.33

c. Equipment Rental:	
Air Compressor, 113½ Hr. @ $2.00	$ 227.00
Gas Shovel (repairs) 349¼ Hrs. share or 56% of $354.96	198.73
	$ 425.78

(3) Total Cost of Base Repairs: $3,835.95
(4) Average Cost per Mile: $491.79

B. Surface
(1) Description of Work:—Relaying mat, edge strengthening and seal coat (by contract).
(2) Cost of Work:

a. Labor: 1748 Hrs. @ .50	$ 874.00
308 Hrs. @ .45	138.60
51 Hrs. @ .40	20.40
	$1,033.00
By Contract, Koss Construction Co.:	
Construction of blotter surface, 7.595 Mi. @ $120.00	$ 911.40
Cost of distributing oil by Fitch's crew, 49,404 Gals. @ .006168	$ 304.73
b. Materials: By contract, Koss Construction Co.:	
1614.151 Tons cover aggregate @ $1.75	$2,824.76
24,216 Gals. Binder Bitumen, SC-7 @ .10	$2,421.60
800 Gals. MC-3 Oil @ .08	$ 64.00
Maint.— 7,834 Gals. MC-2 Oil @ .0574	$ 449.67
" 7,848 Gals. MC-2 Oil @ .0556	436.35
" 30,091 Gals. SC-2 Oil @ .0412	1,239.75
" 1,090 Gals. SC-2 Oil @ .0396	43.16
" 12,822 Gals. MC-3 Oil @ .0556	712.90
59,685	$2,881.83
" 414 Cu. Yds. Limestone @ 2.10	869.40
	$3,751.23

c. Equipment Rental: None
(3) Total Cost of Surface Repairs: $11,310.72
(4) Average Cost per Mile: $1,450.09

C. Equipment (Charged against Unit 4 during current year).

(1) Roller	$ 212.00
No. 10 Lessman High Lift Shovel, 1/18 share	96.39
Spray Unit	678.15
Hargrave Road Disc & American Spray Unit, 7.3 Mi. @ $68.03	496.62
Cost of bituminous surfacing equipment paid to Gen. Maint. Acc't., 7.8 Mi. @ $26.16	204.08
(2) Total Cost of Above Equipment	$1,687.24
(3) Average Cost per Mile	$ 216.31

D. Average Cost per Mile

$$\frac{\$15{,}900.51}{a + b + c} \div \frac{7.8}{\text{Total Miles in project.}} = \frac{\$2{,}038.53 \text{ Ave. Cost per Mi.}}{}$$

Maintenance Dept. 1935 Aug. 8th. to 24th.
Iowa State Highway Commission Road Oil Div.

WEST UNION

FAYETTE WINNESHIEK COUNTIES

CALMER
Highway 11

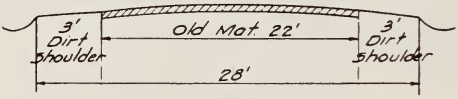
Length : Winneshiek	7 57	Miles
Fayette	8.61	"
	16.18	

WORK: Prime shoulders 7' wide-including 4' under strengthened shoulders
Mat shoulders to be strengthened 4' wide on each side.
Outside dirt shoulders primed 3' wide

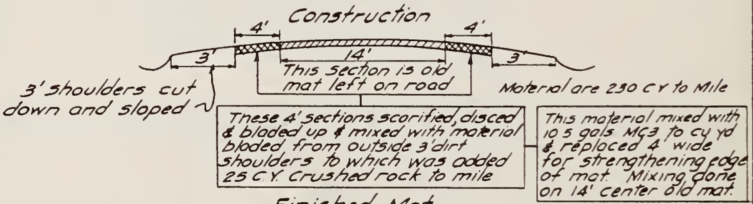
Preliminary Work Frost Boils - July 11th. 1935.

Series of Frost Boils - total lin. ft. 5200. Broomed and primed with 40 gallons of MC2.
600 Yds. crushed rock in one windrow North of Turkey River was mixed with 14.5 gallons MC3 to cubic yard. Mixture then hauled to frost boils, spread and rolled 22' wide.
On some frost boils, old mixed stock pile material was used for mat.

Road Before Construction



Construction



This section is old mat left on road

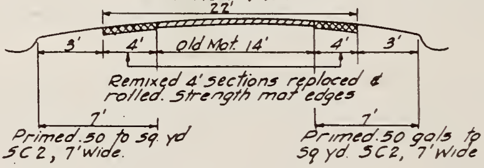
3' shoulders cut down and sloped

Material are 230 C Y to Mile

These 4' sections scorified, disced & bladed up & mixed with material bladed from outside 3' dirt shoulders to which was added 25 C.Y. Crushed rock to mile

This material mixed with 10 5 gals MC3 to cu yd & replaced 4' wide for strengthening edge of mat. Mixing done on 14' center old mat.

Finished Mat.



Remixed 4' sections replaced & rolled. Strength mat edges

Primed .50 to sq. yd SC 2, 7' wide.

Primed .50 gals to sq yd. SC 2, 7' wide

OIL USED

				Gallons
PRIME	MC 2	Cars	1	9800
"	SC 2		4	32703
BINDER	MC 3		2	17807
	TOTAL		7	60310

ANNUAL RECORD OF MAINTENANCE OPERATIONS

For Bituminous Surfacing Projects
Jan. 1, 1936, to Dec. 31, 1936

County, Winneshiek; Road No. 11; Miles, 7.8; Constr. Proj. P-177

A. Base

(1) Description of Work—Frost boil treatment.

(2) Cost of Work—

(a) Labor	$ 87.30
(b) Material (drain tile)	13.50
(c) Equipment rental	None
(3) Total Cost of Base repairs	$100.80
(4) Average Cost per Mile	$ 12.92

B. Surface—

None

C. Equipment (charged to unit 4 during 1936)

(1) Baker disc model, 149-A	$516.67
Roller (concrete)	212.62
Material Spreader	294.78
Less credit for roller transferred to Fayette County	212.00
(2) Total Cost of the Above Equipment	$812.07

D. Average Cost per Mile—

912.87 divided by 7.8 equals 117.03, average cost per mile.

a+b+c

Suppose we analyze the expenditures shown on pages 532 to 543, inclusive. Immediately the difference in mileage on pages 533, 539 and 540 as compared with pages 541 and 543 is evident. This difference is due to the fact that after the original 7.4 miles was constructed an additional .4 mile was built in the Town of Calmar, thus making a total of 7.8 miles of bituminous surfaced road.

It might be interesting to go into the history of this particular road before the analysis of the maintenance expenditure is made.

The surface consists of a mat 1½″ to 2″ thick constructed in 1932 on the existing base which had previously been graveled. Some loose gravel was on the shoulder at the time of construction. The mat was a blade mix job and laid 22′ wide to a feather edge. The base was primed at the rate of four-tenths gallon per square yard. Page 539 shows the construction cost.

During 1933 the shoulders were primed and 252 cubic yards of stock pile material mixed up. Page 540 shows this expenditure as well as the accumulated construction costs which total $2315.00 per mile.

During 1934 only regular maintenance was applied. No record of maintenance operations has been included in the paper for 1934.

During 1935 approximately $3800.00 was spent for frost boil treatment and approximately $1700.00 for new equipment. The outside four feet of the mat had broken up due to the feather edge type of construction, tractor traffic and a base that was not adequate to carry the traffic. The bitumen was badly oxidized. This eight feet of mat was remixed with additional bitumen, the base and shoulders primed and the mat relaid. The entire surface was then given a seal coat consisting of one-fourth gallon of bitumen per square yard and twenty-five pounds of one-half inch maximum sized stone chips. Pages 540, 541 and 542 cover these details.

During 1936 only regular maintenance was applied except some additional frost boil treatment and additional equipment purchased as shown on page 543.

During 1937 only regular maintenance will be required, except about 400 feet of frost boil treatment.

Proceeding with the analysis we find that pages 532 and 533 show the following yearly average of maintenance expenditure for this road:

Maintenance Proper	
Surface	$346.00
Road Bed	55.00
Structures	58.00
Snow Removal	215.00
Betterments	
Road Bed	$ 18.00
Total, per mile average	$692.00

Page 543 shows an average cost per mile of $117.00. Taking this amount from Surface—Maintenance Proper ($346.00) and we have $230.00 per mile as the regular routine maintenance expenditure made on this road for the year 1936.

Each year's maintenance expenditure can be broken down and analyzed in the same manner. It will be noted that new equipment is charged off completely in the year which the expenditure is made. Some states charge a rental for each item of equipment. The total equipment expenditure should be the same over a period of years.

In final conclusion it is the earnest hope of the writer that a system of cost keeping can be developed and adopted in all the states so that comparisons of maintenance costs can be made on a comparable basis.

Successful Methods and Types of Traffic Striping for Bituminous Surfaces

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The Missouri Highway Department has placed a white stripe on high type bituminous surfaces for the last four years. In all cases this has been a solid stripe, using about 20 gallons of material for a stripe 4″ in width and 30 gallons for a 6″ stripe. The 4″ stripe is used on all two and three lane pavements, while the 6″ stripe is used as a centerstripe on four lane pavement with 4″ side stripes.

The solid 4″ stripe costs slightly over $31.00, of which $28.00 covers the cost of the white paint with a Labor and Equipment cost of $3.34. The Labor and Equipment covers the salary and subsistence of full time men, the cost of extra labor, and miscellaneous expense, such as flags and blocks placed on the freshly painted line, the centerstriper, small pickup used for transporting men to and from work and in picking up the blocks from the dry line; together with the cost of a 1½ ton truck used for applying additional paint required during the day. For every mile of stripe placed our past experience has proved that the centerstriper is used approximately 4 miles, the 1½ ton truck 5 miles, and the small pickup 13 miles. The heavier equipment is ordinarily left in the field at the end of the day's work, and the small pickup is used in transporting the men to some nearby community where fair facilities can be provided for meals and lodging.

The white paint used in all striping work is made up according to our own standard specifications. A copy of these specifications is attached. This material dries in from 15 to 45 minutes, depending entirely upon the thickness of the film applied upon the blacktop surfacing. When applied at the rate of 20 gallons per mile on a 4″ stripe, this line can be driven across at right angles within 15 minutes time without tracking. In the case of traffic following along the centerline it takes from 30 to 45 minutes to dry without picking up.

This particular material has given us from 6 months to 3 years wear, depending, of course, entirely upon the abrasive action caused by traffic. Around St. Louis, where traffic is heavy, we get approximately 6 months service when applied on concrete and one year's service when applied on bituminous pavements. In rural sections with light traffic, we get from two or three years service. During 1936 380 miles of solid stripe was placed.

For several years there has been a demand on the part of the driving public for some sort of centerstripe on the low cost bituminous surfaces. Due to the fact that some of these surfaces bleed during the heat of the summer and have to be resealed and maintained during the summer months, we felt that the use of stripe costing from $30 to $35 a mile was not justified when we considered that most of the low cost bituminous surfaces were on the lighter traveled highways and that we could probably not expect to obtain over 6 to 8 months service from a stripe due to the fact that resealing, maintenance operations, or bleeding would obliterate any remaining stripes. About two years ago we conducted some experiments in the placing of a broken line, and developed a more economical method of placing a centerline. From past experience we found that spotting a centerline, in order to give the equipment driver something to use as a guide for steering his equipment on the exact center, cost about $7.00 a mile. We desired to eliminate this particular feature of striping a bituminous surface, and found that with a fair amount of practice a good driver could steer within 6″ of the center of the road surface. We feel that this is entirely satisfactory for our particular purpose.

Late last fall we decided to place a broken dot and dash white centerstripe on all of the low cost bituminous surfaces. During the fall 1,815 miles of this type of line was placed and the reaction from the traveling public was exceptionally favorable. The white dot is approximately 20 feet in length, while the blank gap is double this length. This was done by letting the paint flow flow during two revolutions of the rear wheel of the striper and leaving the paint flow shut off during four revolutions. This striping is done at a rate of approximately 12 miles an hour, and it was found that an operator could not react fast enough to adjust the dot for one revolution of the rear wheel. Various lengths of stripe and gap were used, and we found that the shortest feasible stripe gave much better visibility at night due to the fact that several stripes were visible within the range of car headlights.

The same specification material as used for solid stripe on high type surfaces was used on the low cost bituminous surfaces. We ordinarily started operations after the heat of the summer and beyond the time when any bleeding could be expected and retreatments had been completed. By this time most of the surfaces had dried out and become stable. The solvents used cause rapid drying of the centerstripe without any excessive solvent effect on the bituminous pavement. There is just enough softening to cement itself thoroughly to the pavement.

In placing the dot and dash system, we used a solid centerline over hilltops with less than 800 feet sight distance and around blind curves or those with less than 300 foot radius. Approximately nine gallons of paint was used per mile of finished stripe. The cost of labor, material, and equipment averaged slightly less than $14.00 per mile for the finished stripe.

Our survey of these traffic stripes during the winter and spring showed that they were of great assistance to night traffic. On ordinary low cost bituminous surfaces there is no definite demarcation between the edge of the pavement and the shoulder, and night traffic has no distinct line to follow at this point. The white centerline shows up especially well at night and is of considerable assistance to traffic. The stripes placed last fall gave good service until May and June when some bleeding and tracking occurred. Our early maintenance on the low cost bituminous surfaces occurs from May to September, and during these months of the year most of these roads will be without the white centerstripe. This cannot be avoided in this type of construction, and all of our efforts have been to develop a low cost stripe which will pay for itself in the six months to eight months service obtained. The Department has experimented with some cheaper type formulas and next year we may be able to reduce costs still more due to a saving of $2.00 to $4.00 a mile in the cost of cheaper formula paint which will give six to eight months service without difficulty.

(Following are the Missouri State Highway Department specifications for White Centerline Paint and for Asphalt Centerline Paint.)

SPECIFICATIONS FOR WHITE CENTERLINE PAINT

The paint shall be homogeneous, well ground, shall not settle badly or cake in the container, and shall be readily broken up with a paddle to a smooth, uniform condition.

All materials used shall conform to the standard specifications of the American Society for Testing Materials, and all tests of such material shall be made in accordance with the methods specified by this Society. Where no such method is specified for the particular material the Department shall prescribe and make such tests as it deems necessary.

Samples adequate for test shall be furnished free of charge by the contractor and no paint shall be made until completion of tests. All ingredients entering into this formula shall be weighed, proportioned, mixed and ground, in the presence of the inspector after his approval of the materials being used.

The gum solution shall be clarified by centrifuging, filtering, by settling or by any other method which meets the approval of the Engineer.

PROPERTIES

Pigment

Pigment shall be Titanox-B meeting A.S.T.M. Specifications D382-35.

Solvent

Raw Tung Oil (ASTM D12-33)	15%	by	Vol.
Normal Butyl Alcohol (ASTM D304-33)	17%	”	”
Acetone (ASTM D329-33)	34%	”	”
Alcohol, Formula No. 1, (Not Less Than 180 Proof)	34%	”	”

Gum Vehicle

Gum, East Indian D.B.B.	35%-37%	by	weight
Solvent (as above)	65%-63%	”	”

Composition

Pigment (as above)	42%-45%	”	”
Gum Vehicle (as above)	58%-55%	”	”

The proper percentage of above ingredients shall be such as to give a paint of the proper spraying consistency.

Add sufficient Prussion Blue in oil to overcome any yellowish tint.

SPECIFICATION FOR ASPHALT CENTERLINE PAINT

Asphalt centerline paint under this specification shall be made of hard native asphalt fluxed with steam refined asphalt derived from an asphaltic base crude, and cut back with a light volatile petroleum naphtha.

Tests shall be made in accordance with the latest ASTM procedures.

It shall comply with the following requirements:

The mixture shall be homogeneous and appreciably free from foreign matter, water or settlement of any kind.

It shall be thoroughly blended and when 200 cc at room temperature is screened through a No. 20 sieve opening (0.833 mm.) shall show no residue retained in form of lumps or deleterious substances.

1. Specific gravity, at 60 Deg. F., not more than............ .95
2. Specific viscosity Saybolt-Furol @ 122 Deg. F.,............60-90
3. Distillation by volume ASTM D 402-34T
   Percent off at 300 Deg. F., Not less than....................20.0
   Percent off at 680 Deg. F., Not more than................60.0
4. Tests on residue from distillation:
   (a) Percent soluble in CS_2 not less than................98.0
   (b) Penetration of residue at 25 Deg. C., 100 gm. 5 sec.. 8-15
   (c) Ductility at 25 Deg. C., not less than................ 3
   (d) Softening Point (R&B) not less than................175°F.
5. (a) When paint is flowed on a standard tin panel it shall show a heavy film and it shall not run off excessively when the panel is set at an angle of 45 degrees. The drying time at 77 Deg. F., shall be such that the film on the tin panel shall set to touch in less than 15 minutes or when applied to a dry concrete pavement a heavy film shall be sufficiently dry within approximately 20 minutes after application so that there will be no pickup under traffic.
   (b) After the film on the test panel is allowed to dry one

(1) hour at 70 to 80 Deg. F., is shall be placed in a vertical position for one (1) hour in an oven at 150 Deg. F., shall show no blistering, running, excessive sagging, separation or slipping.

(c) The same test panel prepared as in paragraph (b) shall be maintained at a temperature of 32 Deg. F., for one hour and when bent rapidly over a one inch mandrel immediately after removing from the low temperature bath the film shall show no spalling or separation from the panel.

THE MOST ECONOMICAL EQUIPMENT FOR SEALING AND RETREADING

The first point to consider in selecting equipment for this type of work is: Is it the best type of equipment for this work and can it also be put to other uses when not on this type work? This is important because equipment that can be used only a short time during the year will be more expensive to operate than equipment which can be used the year round. This is especially true of equipment which is on a rental basis that must be depreciated over a certain period of time.

A typical list of equipment for a crew doing this type of work would be as follows:

Distributor—400 to 500 gallon capacity.
Four to Six Supply Tanks—Should be insulated.
Asphalt Pump—Should be mounted on 2-wheel trailer.
Heater—Two tank car capacity.
Mechanical Spreader.
Roller—3-Ton motor driven patch roller.
Rotary Broom—May not be necessary.
Motor Patrols and Trucks to be picked up near location of work as needed.

This equipment will be sufficient for a crew doing light retreading and seal coating work.

A small distributor is preferred, because the first cost will be considerably less and a ton and half or two ton truck of one of the popular makes will handle it very readily. A small distributor can also be used economically for patch work on bituminous pavements and for pouring cracks in concrete pavements during the winter months.

Supply tanks mounted on skids which will slip into the bed of a ton and a half truck are desirable, as materials can be hauled this way on hired trucks much more economically than it can be hauled in the distributor. The distributor can thus be in actual operation more hours per day than when it must be used to transport materials from the tank car. A 400-gallon distributor can pour upwards from 20,000 gallons per day if sufficient supply tanks are on hand. Supply tanks should be insulated so that short delays on the job will not necessitate reheating the material in the distributor. All materials should be heated to pouring temperatures in the tank car if possible to do so.

It has been my observation that a motor patrol grader in the hands of a skilled operator will do as good a job of mixing and spreading as any multiple blade machine. It is also more economical to operate and can be readily and economically moved from one job to another. Crawler type tractors are more expensive to operate and considerably more trouble to move from one job to another.

Most of the equipment listed above can be used the year round and is of such type that it can be quickly transported from one job to another. None of it would have to be shipped by rail, which is important when a hurry-up job is to be done.

A rotary broom may or may not be necessary equipment. It is, of course, desirable to have the surface to be treated as clean as possible before applying bituminous material. During the summer months when rains are infrequent, very little dirt is tracked in on the surfacing and brooming is not very often necessary.

Equipment, to be really economical, should be, as stated above, capable of being used during the entire year; should be such that it can be transported from job to job quickly and easily; should be suited for the work it is intended for; and should be of such capacity that it will do the work intended for it. In other words, it would not be economical to have an 800-gallon distributor when a 400-gallon distributor would do the work. Highly specialized equipment usually has a short working season and is, therefore, costly to have around.

Another important factor to consider on equipment of this type is the experience of the manufacturer of this equipment and how widely it is used. Any equipment will break down some time or other, and parts will be needed for making repairs. On the more popular types and makes of equipment parts are usually carried in stock at numerous branch offices and can be quickly obtained, where with some of the less used types and makes, parts must be ordered from the factory. Also, you may find that you have an orphan on your hands after a short time.